1998

The Compression strength comparison of corrugated shipping containers, printed by thick and thin plate

Worawut Sriratbunterng

THE COMPRESSION STRENGTH COMPARISON OF CORRUGATED SHIPPING CONTAINERS, PRINTED BY THICK AND THIN PLATE

By

Worawut Sriratbunterng

A THESIS

Submitted to
Department of Packaging Science
College of Applied Science and Technology
Rochester Institute of Technology
Rochester, New York

In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

1998

Department of Packaging Science
College of Applied Science and Technology
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

M.S. DEGREE THESIS

The M.S. degree thesis of
Worawut Sriratbunterng
has been examined and approved
by the thesis committee as satisfactory
for the thesis requirements for the
Master of Science degree

Karen L. Proctor

Barry A. Lee

Daniel Goodwin

Date June 10, 1998

THE COMPRESSION STRENGTH COMPARISON OF CORRUGATED SHIPPING CONTAINERS, PRINTED BY THICK AND THIN PLATE

DEDICATION

This thesis is dedicated to my parents, Chavalit and Vichitra Sriratbunterng. Their love and support made this thesis and all my accomplishments possible.

ACKNOWLEDGMENTS

There have been a lot of people who have provided support and contributed to this research. I am grateful to each of them for their support and encouragement.

My most heartfelt thanks to my major thesis Professor Karen L. Proctor for her patient guidance and dedication throughout the project. Also, my appreciation to the committee members, Dr. Daniel L. Goodwin and Professor Barry A. Lee, for their technical reviews and assistance.

I also wish to thank Professor Anne Barker for her advice and assistance on the statistical analysis. My sincere thanks also goes to all the writing lab instructors at the English language center for editing my papers.

My sincere appreciation goes to the following organizations and people. Without their help, this project would have been impossible to complete within the required time frame.

RDA Container Corporation, Rochester, NY., specifically Peter Netter and Michael Mangione, for providing this project with the sample containers and the production time.

Mark/Trece Inc., Baltimore, MD., specifically Donald G. McCaughey Jr., Bob Demetrician and Michael Gardiner, for providing me with the technical information about the printing plate, and providing the printing test plates for this project.

SunChemical, Philadelphia, PA., specifically Steven J. Dalbey, for supporting this project with the printing inks.

Finally, I wish to thanks all the unnamed operators who helped me throughout this project.

ABSTRACT

THE COMPRESSION STRENGTH COMPARISON OF CORRUGATED SHIPPING CONTAINERS, PRINTED BY THICK AND THIN PLATE

BY

WORAWUT SRIRATBUNTERNG

1998

The objective of this study was to examine the effect of direct flexographic printing on the compression strength of the RSC style containers when high quality graphics were printed, using thick and thin plate technology. Three factors were studied including: 1) different plate technology (thick and thin), 2) number of colors being printed (one and three), 3) printing impression (light and heavy). The compression strength comparison of the preprint and the postprint were also examined.

The results showed that using the thick plate technology caused a significant reduction in the compression strength of printed containers, compared to either preprint containers or containers printed by using the thin plate technology. With the thick plate technology, printing more colors on corrugated containers resulted in a significant reduction of the containers' compression strength. Because of the compressible backing material used in the thin plate technology, the strength of printed containers was highly maintained. This allowed box manufacturers to print more colors on containers without significantly decreasing their compression strength, even when printed with a large surface area and on all four panels.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

1.0 INTRODUCTION

In the early days of the corrugated industry, very little printing was needed (Fibre Box Association, 1992). The primary purpose of printing on corrugated containers in the past had been to provide identification and to make it easier to sort the product. The main function of corrugated containers was only to contain and protect the product from forces that occur during the handling, storage and shipping (Koning, 1995).

Today, corrugated containers are no longer only protective shipping cartons. Marketing directors, purchasing agents and end users are looking to the corrugated containers not only to safely carry and warehouse the product but also to promote and sell the product in retail stores (McCaughey, 1995). This makes the printed graphic design on corrugated containers more important.

Changes in distribution and retailing demands on corrugated containers increase the demand for more and more colorful high quality printing on corrugated containers (Fibre Box Association, 1992). The use of corrugated containers as retail packages for some consumer products is growing (Bakker, 1986). For example, many products, such as electronic appliances and hardware that frequently remain in their shipping containers at the point of sale. This calls for higher printing quality on corrugated containers so they can also serve as promotional sale tools. More attractive and colorful photographic printings are used on corrugated containers to help sell merchandise (Bessen, 1990).

Consequently, every corrugated container is now expected to do double duty, to be more than just protection for a product during shipping. Some containers are point-of-sale displays, enticing customers with bright colors and fancy graphics. Some containers are their own sales messages, offering detailed product information as shoppers compare brands in the store. Some containers also serve as the assembly instructions and owner's manual for the product. All, however, share one requirement: high quality printing (Maynes, 1992).

In the corrugated board industry, there are currently three major printing processes: flexographic printing, offset printing and screen printing. Flexographic printing, however, is the most common printing method used in the corrugated industry. It is used by the corrugated board industry either to print the liner before the manufacturing of the board (preprint) or to print the board blanks during the board converting process which is called postprint or direct print (Jonson, 1993).

Kelley (1992) defined high quality graphics on corrugated containers as line or process work with three or more colors. High quality line work requires printers to be able to print the smallest six-point type in both positive and reverse copy. Process work can be three- or four-color screen combinations that recreate an illustration or reproduce a photograph.

During the early 1980's, postprint was used for printing only one or two color simple graphic designs on corrugated containers. At the same time, the preprint of linerboard was commonly used for applying high quality complex graphic designs on corrugated containers (Share, 1992). It was always used to print fine line work and three or more color process work. The printing quality of preprinting liner board is closest to the litho label quality (McCaughey, 1995).

Preprint has some disadvantages. The large amount of both set-up time and start-up waste required to prepare the corrugater to run preprint makes this process uneconomical for short volume printing. The demand for high quality printing is usually present for smaller orders which cannot justify preprint. The point at which preprinted liner is more economical than direct print on corrugated board is probably around three to six rolls, depending on the complexity of the job. Preprint slows production speed on the corrugater. Preprint often creates more waste and more expensive waste as well (Eldred, 1993). Printing plates for preprint are also very expensive and require long lead time to make.

Recently, postprint on corrugated board has been rapidly gaining in quality (Reynolds, 1992). According to Schwartz (1994), more color flexographic postprint corrugated presses have been installed in the last five years. The new presses, with their improved performance capabilities, are the important tools required to produce consistent high quality advanced postprint graphics to compete with the quality look of preprinted linerboard. The minimum job run of the postprinting process is also more flexible than the preprinting process.

Direct print on the combined corrugated board, however, reduces the structural strength of finished corrugated containers. This strength is critical because it determines containers' ability to protect the content and to survive the hazards of the distribution system. According to Wright, McKinlay and Shaw (1988), compression strength of corrugated containers is the most recognized measurement of their structural performance.

Direct flexographic printing applies pressure to the corrugated board to effect ink transfer. The pressure that is needed to transfer inks from printing plates to the board could crush the corrugated flutes (Soroka, 1995). Corrugated board can also be crushed as the board passes through nip rolls during conversion (Wright, McKinlay and Shaw, 1988). The crushed board will be thinner and less stiff. Most importantly, compression strength of corrugated containers may be impaired if the printing crushes the flutes along an entire panel (Bessen,1990). According to Diethorn (1996), at least fifty percent of all corrugated containers produced in the United States are compression sensitive and a full twenty percent are subjected to customers' compression specification. Thus, the goal in printing should always be to minimize board crush.

Soroka (1995), recommended that heavy and multiple color ink coverage should be avoided where the compression strength needs to be maximized. However, high quality graphics always involve large amount of print coverage and multiple colors. When considering the effect of postprint and preprint on the compression strength of corrugated containers, preprint impairs less compression strength of corrugated containers than postprint does. For preprinted corrugated containers, linerboard was printed before being combined with the single face at the corrugater. This eliminates the possibility of board crush due to the printing process. In contrast to preprint, postprint applies graphics directly on the combined corrugated board, causing the board crush and diminishing the compression strength of finished corrugated containers.

Recently, thinner sheet photopolymer plates mounted on compressible backing materials have been introduced to the flexographic industry. The main objective of using thinner plates and compressible backing materials together is to improve the print quality. Though, there is another advantage which may improve the strength performances of printed corrugated containers by less flute crush during printing. According to Arimond and Koss (1995), when the compressible backing material is used, it will take the brunt of impression during the printing process. Consequently, printing impression can be applied to corrugated board without risking board crush. The reduction of board crush may maintain the compression strength of post-printed corrugated containers.

This study examines the use of recently developed printing plate technology to flexographically apply graphics on corrugated shipping containers and its effect on container' performance. The objectives of this study are the following:

1) To evaluate the effect of direct flexographic printing on the compression strength of the RSC style corrugated containers when high quality graphics were printed, using conventionally thick plate and thinner plates mounted on compressible backing materials.

2) To compare the compression strength of preprinted and postprinted corrugated containers.

3) To evaluate the effect of applying three-color process graphics on the compression strength of corrugated containers.

2.0 LITERATURE REVIEW

2.1 Corrugated Shipping Container

Corrugated containers are the most widely used and most versatile distribution shipping containers. In 1988, more than 300 billion square feet of corrugated board were converted to boxes with an estimated market value of $12 billion (Flexographic Technical Association, 1991). The key to the growth of this industry was the approval by the railroads to replace wood boxes for shipping many commodities (Bakker, 1986).

2.1.1 The Corrugated Structure

A corrugated board is made from two or more sheets of liner paperboard and one or more fluted sheets of corrugated medium. When the corrugated board is made up of two liner paperboards bonded to a fluted or corrugated medium, it is called a single wall. The single wall corrugated board is the most common board used for corrugated shipping containers. According to Bakker (1986), the single wall accounts for about ninety percent of all corrugated shipping containers produced in the United States. The combination of two mediums and three facings is call a double wall. There are also the other constructions of corrugated board i.e., single face, triple wall, which serve for a different purpose of usage.

Almost all the liner board for corrugated board made in United States today is an unbleached kraft. The bleached kraft liner board is more expensive than an unbleached, but is occasionally used when the container is displayed and a high quality printing is required.

Linerboards come in a variety of weights, which range in the United States from 26 to 110 lb/1000 ft^2. The most commonly used linerboard in United Stated is 42 lb/1000 ft^2. The range of standard weights is shown in Table 1. The most widely used grade of semichemical medium is 26 lb/1000 ft^2. About 20% of medium used is made from recycled liner board and paper (Bakker, 1986).

Grading of the corrugated board is determined by the type and weight of components used in the construction of the board. The most common and universally accepted method of grading a corrugated board is by the bursting strength expressed in pound per square inch (Friedman and Kipnees, 1977). The instruments used to determine the bursting strength are known as the Mullen tester. In addition to the bursting strength method, there is an optional method for grading corrugated board by using the edge crush strength (ECT) expressed in pound per inch width. The mullen test and edge crush test designation for grading corrugated board is taken from the Rule 41 of the rail regulation and from the Item 222 of the truck regulation. The most commonly used single wall board for corrugated shipping containers in the United Stated is 200 lb/inch^2 mullen test with the weight of components of 42-pound outer liner, 26-pound medium and 42-pound inner liner (Bakker, 1986).

The corrugated board for the distribution container is normally made in one of three flute sizes, designated A, B, and C. Standard U.S. corrugated flutes are shown in Table 2. According to Koning (1995), the most commonly used fluted in the United Stated is the C-flute. There are, however, other flute sizes available in the market which adapt the material to numerous grades (Jonson, 1993).

Table 1 : Standard Linerboard Weights

U.S. standard weight, lb/1000 ft2 (g/m2)	Metric standard weight, g/m2 (lb/1000 ft2)	% of U.S. production
26 (127)	125 (26)	5
33 (161)	150 (31)	11
38 (186)	175 (36)	7
42 (205)	200 (41)	50
69 (337)	300 (61)	21
90 (439)	400 (82)	4
other		2

(Bakker, 1986)

Table 2 : Standard U.S. Corrugated Flutes

	Flutes per linear foot	Flutes per linear meter	Flute Thickness in.(mm)
A-flute	33+/-3	108+/-10	3/16(4.8)
B-flute	47+/-3	154+/-10	3/32(2.4)
C-flute	39+/-3	128+/-10	9/64(3.6)
E-flute	90+/-3	295+/-13	3/64(1.2)

(Bakker, 1986)

2.1.2 Styles of Corrugated Containers

One of the major advantages of corrugated board is the ease by which it can be shaped into numerous styles of containers A number of container styles have been reproduced and used in the market. According to Fibre Box Association (1992), styles are grouped into the following broad categories: slotted style, telescope box, slide-style box, rigid box, folder, self-erecting box, interior form and display.

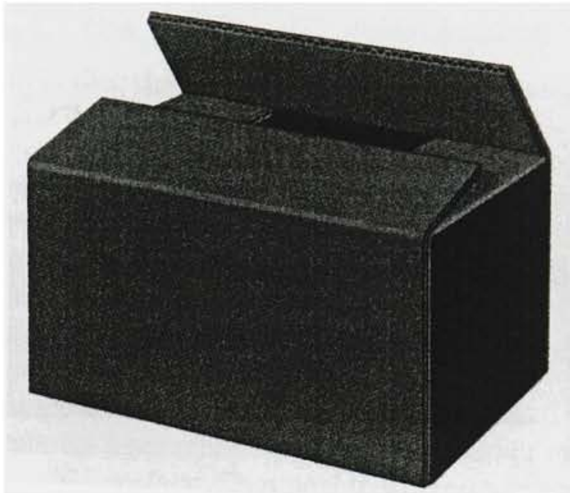
Slotted style containers are generally made from one piece of corrugated board. The corrugated blank is scored and slotted to permit folding. A joint is formed by the container manufacturer at the point where one side panel and one end panel were brought together. Containers are then shipped flat to the users (Fibre Box Association, 1992).

According to Friedman and Kipnees (1977), the regular slotted container (RSC) style with a glued manufacturer's joint is the most generally used for the distribution container than any other slotted style because it is the most economical style of corrugated containers. The RSC style container is predominantly used by industries where the product is being relied upon the container to carry the stacking load (Peleg, 1985). For the RSC style container, all flaps are the same length and the outer flaps meet at the center of the box, the inner flap do not meet. The RSC style container and its box blank are shown in Figure 1.

2.1.3 Compression Strength of Corrugated Containers

One of the most important functions of corrugated containers is to withstand superimposed loads encountered in warehousing and transportation. Recent trends in increased warehouse heights (20, 24 and 30 ft) permissible through the use of palletized handling, have greatly increased the importance of stacking strength on corrugated containers (Friedman and Kipnees, 1977). Because of this hazard, the compression strength of corrugated containers is primarily important. When the product is load bearing, the compression strength of the container is generally not too important. However, many products can only carry a portion of the compressive forces and then the container's compression strength is very important (Koning, 1995).

There are many basic approaches which were constructing a mathematical prediction model of corrugated containers' compression strength. One of the most well-known formula used for predicting compression strength of corrugated containers was developed by R.C. McKee. The formula relates the ultimate compression strength of the RSC style containers to the board caliper, the container perimeter and the edgewise compressive strength of the corrugated board (Peleg, 1985). McKee found



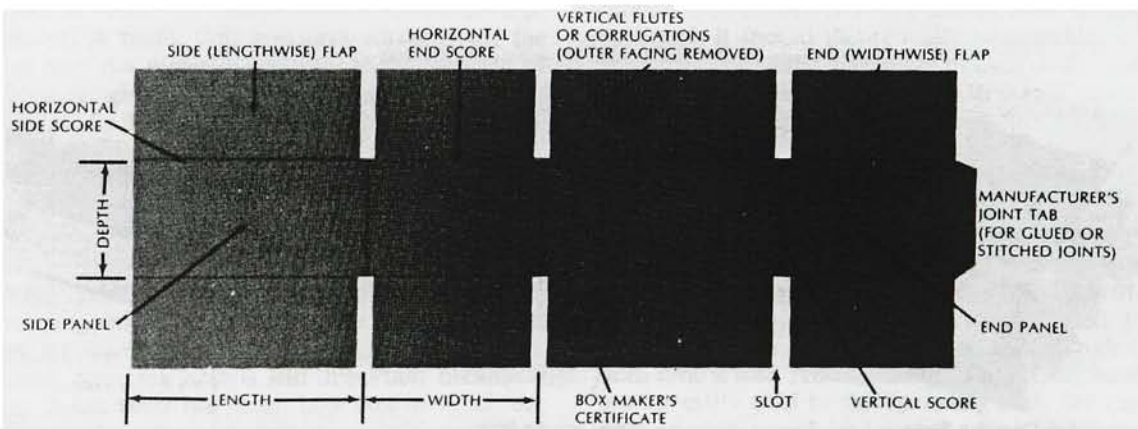


Figure 1 : RSC Style Corrugated Container and Its Box Blank
(Fibre Box Association, 1992)

that the centermost sections of the panels, as compared to the corners, carry only 1/2 to 2/3 of the load. Thus, McKee concluded that the maximum compression strength of the container is ultimately reached when the board fails near a corner of the panel. The stress distribution around the edges of corrugated container under load is shown in Figure 2.

There are a number of distributing and handling factors that affect compression strength of corrugated containers, i.e. environmental conditions, duration of load, warehouse handling, stacking pattern and pallet overhang (Peleg, 1985). These factors have been studied with conclusive results on how they relate to and affect the compression strength of corrugated containers.

The direct flexographic printing affect the compression strength of the printed containers as well. A few studies have been done on how the direct flexographic printing will affect the compression strength of corrugated containers. Container-Quinn Laboratories had studied how the amount of printing on corrugated containers would affect their compression strength. The results are shown in Figure 3. Eyre and Kaczor (1990) also studied the effect of flexographic printing on the compression strength of corrugated containers. They concluded that printing a large surface area, and with more panels and/or colors had a significant

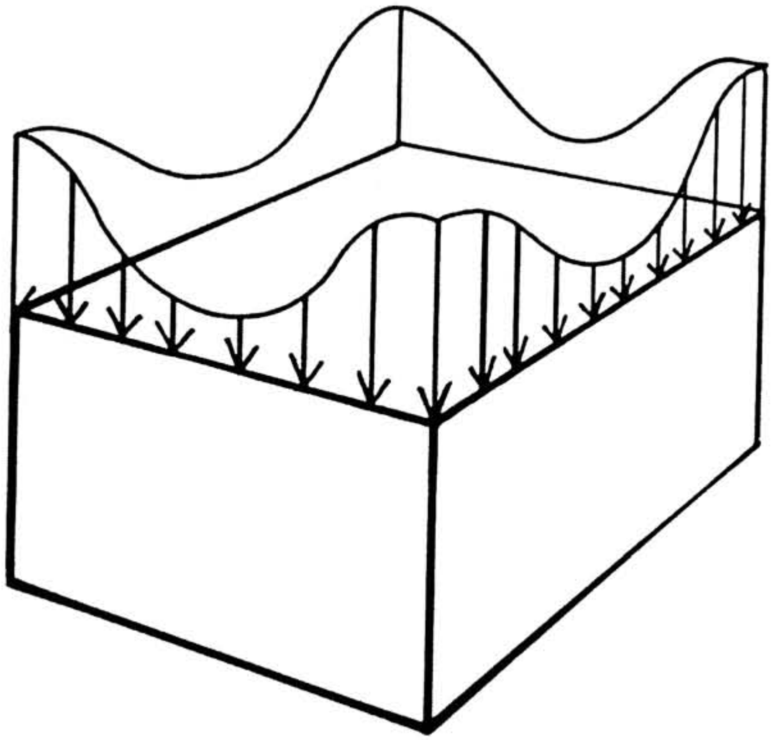


Figure 2 : The Stress Distribution around the Edges of
Corugated Container under Load
(Markstrom, 1988)

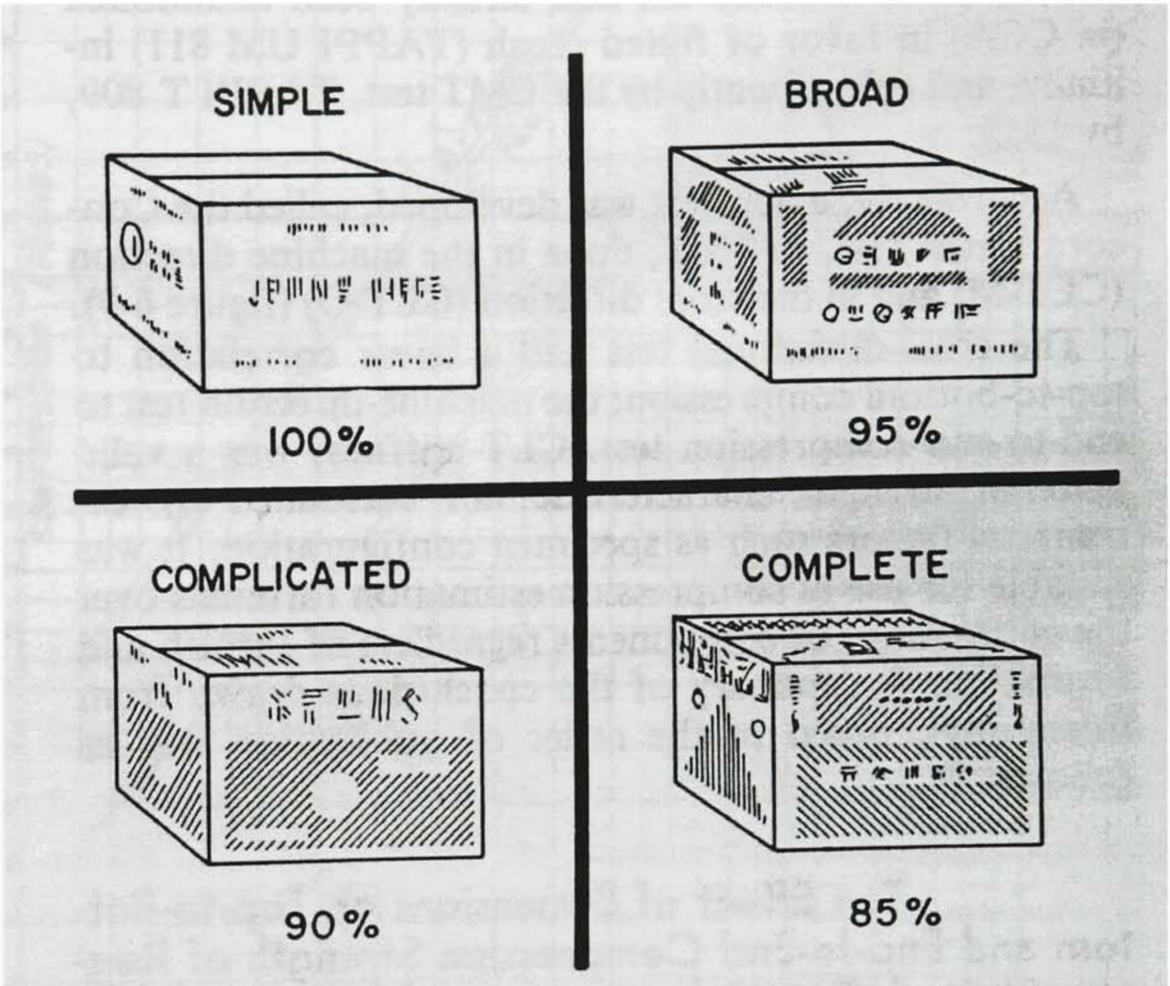


Figure 3 : Effect of amount of Printing on the Compression
Strength of Corrugated Containers
Illustration Courtesy Container-Quinn Laboratories

reduction in the compression strength of corrugated containers.

The compression strength is measured according to a standardized test method and is generally designated the box compression test (BCT) value (Markstrom, 1988). A number of test standards describe in detail how the testing and reporting shall be carried out i.e., FEFCO No50, TAPPI T804, ASTM D 642-90 etc.

The BCT measurement of a corrugated container is established by the compression tester. The empty container is placed between flat parallel plates, which are moved with a constant compression rate of 10-13 mm/min. The force and strain are recorded continuously until the compression failure occurs. The maximum force recorded is noted as the compression strength or the BCT of the corrugated container (Jonson, 1993). The test is carried out in a standardized atmosphere, 23°c and 50% RH. Since the compression strength of corrugated containers is very sensitive to the moisture content variation, a control of the test atmosphere is important.

Paperboard is a hygroscopic material. This means that paperboard will absorb and lose moisture according to the ambient relative humidity (RH) and temperature. The equilibrium moisture content of paperboard will vary slightly depending on whether the equilibrium point is reached from a humidity that is lower than or higher than the current humidity. Thus, two equilibrium moisture contents determined by increasing the humidity around a dry paper sample and by drying a moisture saturated paperboard sample. This effect is known as hysteresis (Soroka, 1995). The hysteresis effect on paperboard is shown in Figure 4.

Because of the hysteresis effect on paperboard, BCT test requires preconditioning and conditioning of sample corrugated containers prior to testing, so that test values are not influenced by ambient conditions at the time and place of testing. Customarily, corrugated containers should be preconditioned at a lower relative humidity than the test conditions (Koning, 1995). Markstrom recommended that the sample corrugated containers should be preconditioned at about 30% RH, then conditioned for a sufficiently long period of time at 23°c and 50% RH. After preconditioning and conditioning, the equilibrium moisture content of the sample containers should be 6-7.5% at 23°c and 50% RH. The recommended preconditioning and conditioning for paperboard are shown in figure 5.

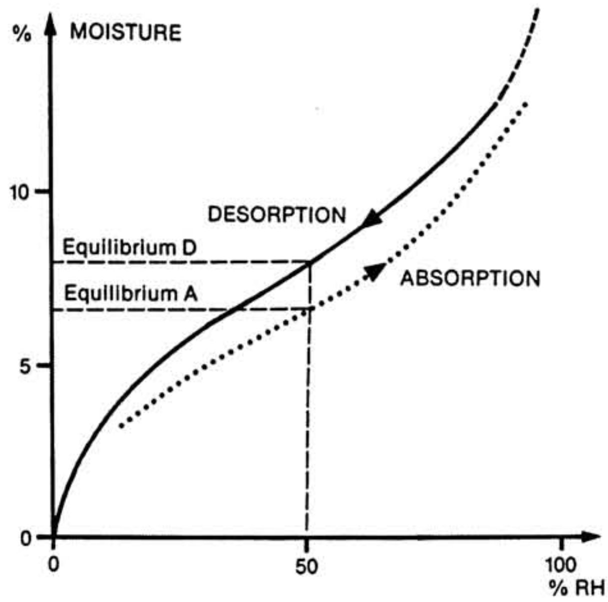


Figure 4 : The Hysteresis Effect on Paperboard (Markstrom, 1988)

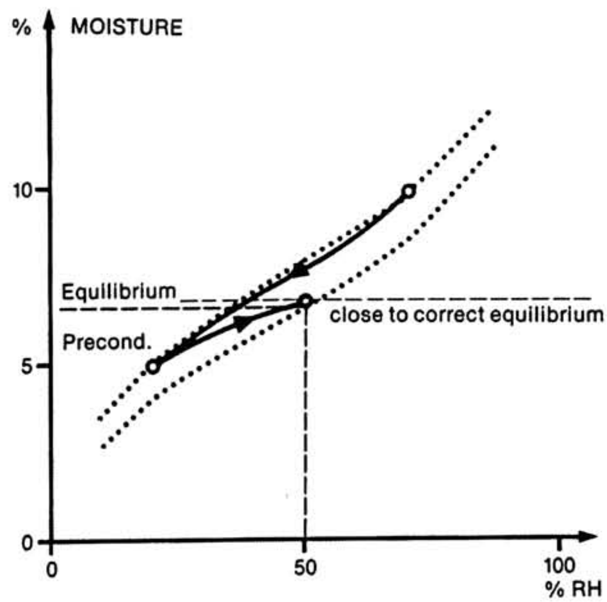


Figure 5 : The Preconditioning and Conditioning for Paperboard (Markstrom, 1988)

2.1.4 Corrugated Board Conversion

In the conversion process, the corrugated blanks come from the corrugater are converted via three types of machine: flexo folder-gluer, flexo die cutter and printer slotter (Jonson,1993). Depending on type of a package to be produced, RSC style containers are mainly produced on the flexo folder-gluer. Diecut packages are normally produced on flexo die cutter. Printer slotter is often used for large packages in short series. The packages produced on the printer slotter will be folded and stapled in separate operations.

In the production of RSC style containers, the flexo folder-gluer takes scored blanks from a corrugated and performs all of the operations to produced finished corrugated containers (Paine, 1991). The flexo folder-gluer will feed a rectangular blank, which it flexographically prints, scores, slots, folds, glues, counts, stacks and even counted bundles at speed up to 300 units per minute. The flexo folder-gluer machine is shown in Figure 6. A recent study shown that seventy to eighty percent of all corrugated containers are made and print on flexo folder-gluer (Bessen, 1990).

2.2 Direct flexographic printing and its effect on corrugated containers' strength

Flexography is a method of direct rotary printing that uses the resilient relief image plates of rubber or photopolymer material. The plates are affixable to plate cylinders, inked by a cell-structured ink metering roll, and carrying a fast drying fluid ink to plates that print onto virtually any substrate (Flexographic Technical Association, 1991).

The flexographic printing system is composed of the following basic components : a) fountain roll, b) ink metering roller (anilox), c) plate cylinder, d) impression cylinder, and e) ink circulation system. The basic flexographic printing system is shown in Figure 7.

The direct flexographic printing process, as employed in the corrugated industry, is essentially the same process as is used in all other flexographic printing, with the exception that the ink used is always water-based, and is never solvent-based (Shulman, 1986). The flexographic inks for corrugated board offer little gloss but good rub resistance and quick drying. There are two groups of flexographic ink for corrugated board: opaque and transparent (Anderson, 1997). Transparent ink will be used when process-color halftone graphics are reproduced.

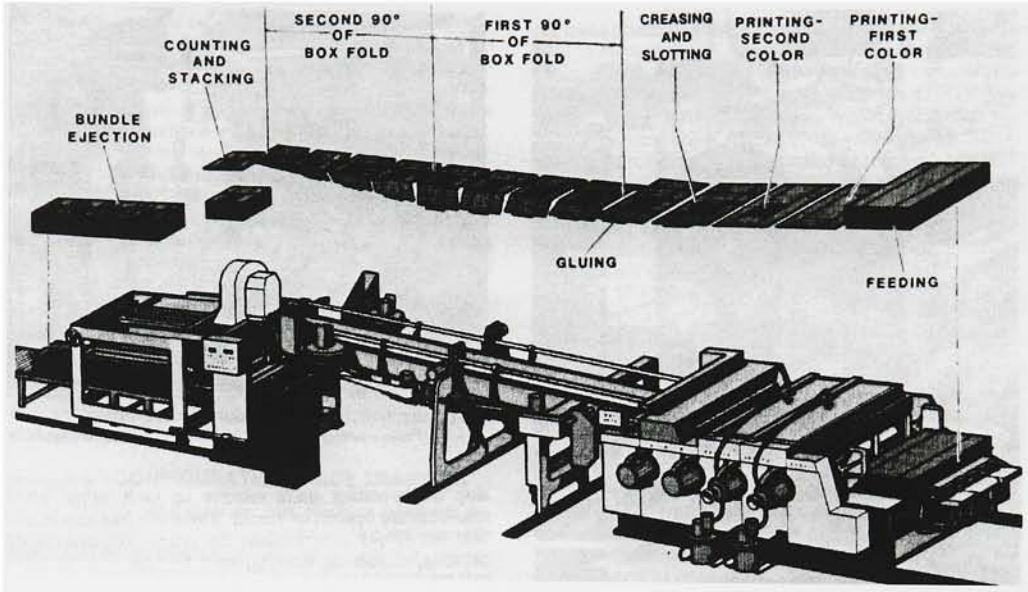


Figure 6 : The Flexo Folder-Gluer (Shulman, 1986)

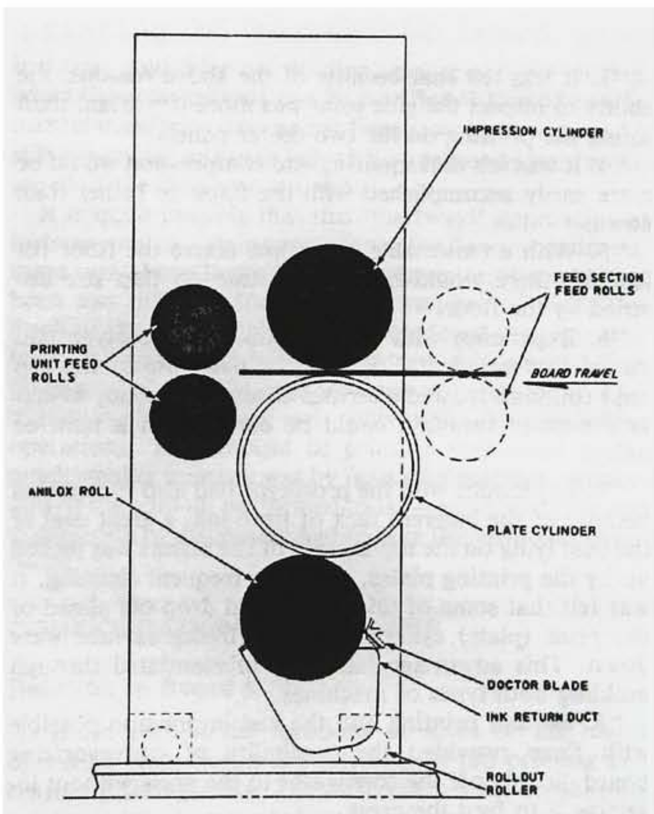


Figure 7 : Basic Flexographic Printing System (Shulman, 1986)

Besides ink, there is another significant feature that distinguishes the direct flexographic printing on corrugated sheet from printing on the other substrates. It is the effect of crushing the flutes (Bessen,1990). The other substrates can be solidly backed up by a steel impression cylinder. Differently , corrugated has only the flute structure to oppose the pressure of printing.

Printing with raised type and image requires that the plate touch the substrate in order to transfer ink. The ideal situation is a kiss impression. Unfortunately, direct flexographic printing on corrugated board sometimes requires a high impression pressure for a number of reasons. The result may end up in crushed flutes. Crushed flutes due to the pressure applied by a printing plate to a container are shown in Figure 8. The flutes' crown can be crushed just a limited amount before the structure fails. According to Diethorn (1996), a very small amount of crush, as little as 0.002″ to 0.005″ could effect the strength and the quality of the board. Crushed sheets make weak containers that result in an unacceptable stacking strength, return shipments, customer dissatisfaction and finally lost business.

Despite the desire to avoid heavy impression, there are conditions that appear to require it i.e., washboarding, runout, plate distortion, etc. Additionally, quality of the machines, such as the inaccuracy of cylinder diameters and their inconcetricity etc., sometimes force the operators to apply more impression at the printing station.

Washboarding refers to the appearance of the single face or double face liner which tends to follow the flute formation, most prevalent in light weight liners (TAPPI,1988). Washboarding on corrugated board is shown in Figure 9. When washboarding occurs, ink has to print in the valley as well as over the crowns of the flutes. Printing plates will make better contact with the flute tips than with the valleys. This occurrence requires more printing impression to overcome the problem (Bessen,1990).

A close look at a corrugated substrate reveals that its thickness is not uniform. The variation of the thickness on a corrugated substrate is called runout (Arimond and Koss, 1995). Corrugated board runout is shown in Figure 10. As the printing nip is closed, the printing plate will kiss the flute top before it can kiss the entire surface to be printed. Direct flexographic printing on corrugated board typically requires more than 0.005 inch nip squeeze to compensate for this runout.

Distortion of the plate's printing surface is generated by the act of wrapping the accurately formed flat printing plate around the print cylinder. As the image is stretched, the plate becomes thinner. This distortion related deformation has a greater effect on the center of the print elements causing a cupping of the print surface (Cusdin, 1994). Distortion of the printing plate is shown in Figure 11. According to MaCaughey (1995), a thicker plate has more distortion than a thinner plate. Again, more printing impression is required to overcome this problem.

From the above mentioned, there are several factors that may force operators to apply an excessive printing impression on to corrugated board while it is directly printed and converted at the flexo folder-gluer. As mentioned earlier, excessive impression at the printing station can cause crushed flutes on corrugated board. When the containers are made from crushed corrugated board, containers will become weaker, thereby affecting the performance, especially compression strength, of the containers in the warehouse, shipping or the other susceptible environments (Wright, McKinlay and Shaw, 1988). Thus, the elimination of crushing is an important factor in maintaining board's quality and the compression strength of finished containers during conversion and printing process.

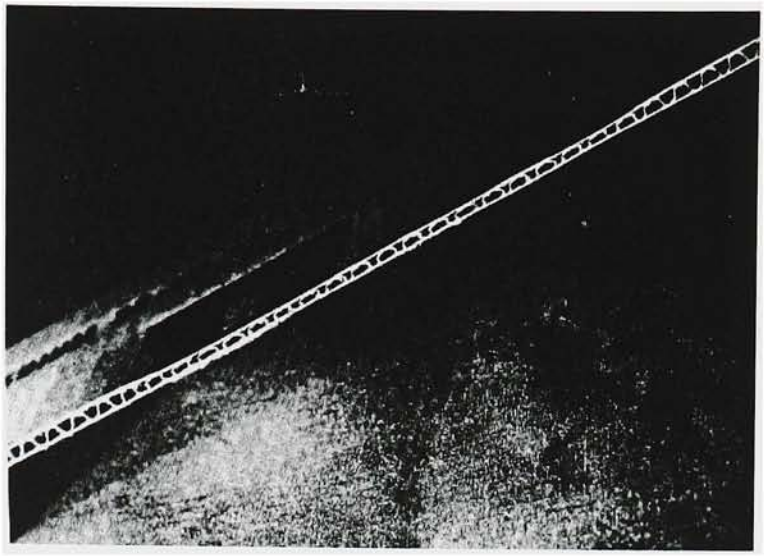


Figure 8: Flute Crush due to Pressure Applied by Printing Plate to the Corrugated Board (Carlson, 1988)

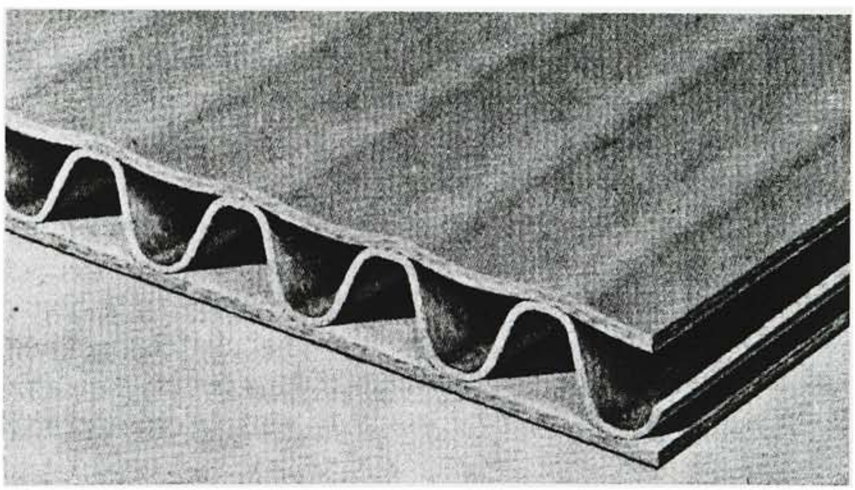


Figure 9 : Closed-up of Washboarding on Corrugated Board (Shulman, 1986)

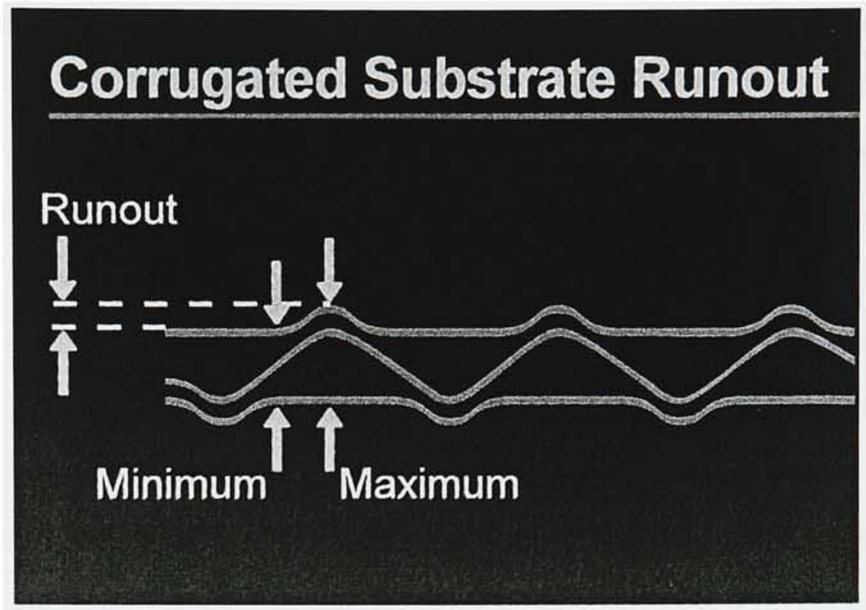


Figure 10 : Corrugated Board Runout (Arimond and Koss, 1995)

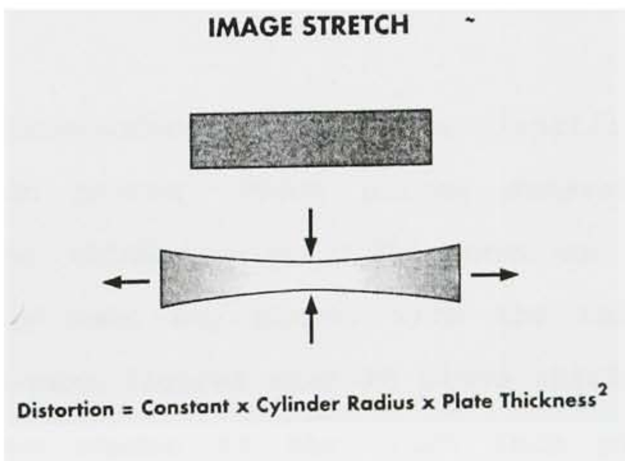


Figure 11 : Distortion of Printing Plate (Cusdin, 1997)

2.3 Flexographic Printing Plate

Graphics on corrugated containers are continually improving as a result of more sophisticated printing presses with improved inking systems and doctor blades, anilox rolls with higher screen count and better plate making materials (Eldred, 1993). The manufacturer of the flexographic printing plate has become revolutionary in recent years. Traditionally, there are two main types of the flexographic printing plate used in the industry: rubber and photopolymer. However, McCaughey (1995) recommended that a photopolymer plate is better for printing high quality graphics. According to Pomerenka (1997), the photopolymer plate itself comes in different types, i.e., liquid or sheet, different durometer, different thickness. Pomerenka (1997) recommended that flexographic printing plate for corrugated board should have durometer between 33-35 Shore A.

Flexographic photopolymer plates can be classified into thick plates and thin plates. Thick plates generally mean any plates with the thickness of 0.250 inch or higher. Thin plates generally mean any plates with the thickness below 0.250 inch. The next logical step in plate thickness is 0.155 inch. It is now common to see 0.125 inch plate (Wojcik, 1995).

Thinner plates are being used more because they reproduce wider tonal range and finer detail. They do not, however, print solid as well as thicker plates unless other things like thin plates are backed by spongy materials to get a greater area of contact between plate and board (Saunder, 1992). Thinner plates also have advantage of being lighter, and when lighter weight sponges or mounting materials are used with them, the result is much better balance of the plates and cylinders. This permits better printing at high speed and they are easier to handle as this makes setups, washing and storage easier and less likely to damage plates.

According to Cusdin (1994), using a thinner plate not only increases the quality of the image on the plate, it also reduces the need for an excessive printing impression to overcome plate thickness distortion and reduces the forces generated in the impression nip. The surface variation of thinner plates tends to be less than those of thicker plates when the plates are mounted.

Since, traditional flexo folder-gluers' cylinders are made to accommodate 0.280″ press undercuts, the mounter must use the appropriate press cylinder build-up material to achieve accurate image position. For the converter, thin plates can be less expensive. But the savings may be fleeting on 0.280″ flexo cylinder because the build-up material may cost more than the total cost of 0.250 inch plate (Wojcik, 1995).

Traditionally, the 0.250″-thick plates are mounted on 0.030″-thick PVC carrier, Mylar (Schwartz, 1997). For thinner plates, the most commonly used build-up material is the compressible polyurethane blanket (Arimond and Koss, 1995). This blanket will act as a shock absorber between the printing plate and impression cylinder. When using a thin plate in combination with compressible backing material, the excess impression will be borne by the cushion. Thus, the possibility of board crush due to the direct print on corrugated board can be reduced.

Ultimately, using the thinner sheet photopolymer plate mounted on the compressible backing material would be the solution for corrugated converters to directly print high quality graphics on containers and to maintain the containers' strength performance as a result of reducing damage to the corrugated board.

3.0 DESIGN OF EXPERIMENT

3.1 Materials

3.1.1 Sample Containers

RSC style containers were used in conducting this experiment. The specifications of corrugated board used were the following:

Flute construction	:	C-Flute
Outer liner	:	Bleached kraft
Inner liner	:	Unbleached kraft
Bursting test	:	200 lbs/1000 feet^2
Minimum combined weight of facing	:	84 lbs/1000 feet^2 (balanced liner : 42)
Dimensions (outer)	:	14″ x 10″ x 9″ (LxWxD)

The outer liner was specified as bleached kraft since the white substrate would allow colors of the reproduced graphics to match colors of the original graphics. Also, the white substrate is usually used when the containers are displayed and high quality graphics are required. In order to print high quality graphics on a corrugated substrate, the printed liner should not weigh less than 42 lbs/1000 feet^2 (Pomerenka, 1997). Thus, the 42 lbs/1000 feet^2 outer liner was selected for this experiment.

The 16″ x 12″ x 11″ dimensions of the container were the standard sizes used for conducting compression test (Maltenfort, 1989). Due to the constraint in cost of printing plate materials, the dimensions of sample containers had to be reduced. The dimensions of sample containers were reduced two inches on each panel so that they were still in proportion to the standard dimensions.

3.1.2 Printing Plate

In this experiment, two groups of sheet photopolymer plates, thick and thin, were used to apply high quality graphics on sample containers. The printing plate with the thickness of 0.250 inch, which was conventionally used in today's corrugated industry, was used to represent the thick-plate group. The printing plates with the thickness of 0.155 inch and 0.125 inch were used to represent the thin-plate group. The use of three different plate thicknesses allowed three separated groups of data to be collected. The specifications of printing plates used were the following:

0.250-inch plate's specification:

Brand	:	Dupont
Product name	:	CYREL TDR
Durometer	:	30 shore A
Thickness variation	:	+/- 0.001 inch

0.155-inch plate's specification:

Brand	:	Dupont
Product name	:	CYREL TDR
Durometer	:	30 shore A
Thickness variation	:	+/- 0.001 inch

0.125-inch plate's specification:

Brand	:	Dupont
Product name	:	CYREL TDR
Durometer	:	30 shore A
Thickness variation	:	+/- 0.001 inch

The plate package setup for three printing plates were the following:

0.250-inch plate's setup:

0.250″ plate + 0.005″ sticky back + 0.030″ carrier sheet (Mylar)

0.155-inch plate's setup:

0.155″ plate + 0.005″ sticky back + 0.120″ compressible backing material (Rogers R-Bak)

0.125-inch plate's setup:*

0.125″ plate + 0.005″ sticky back + 0.030″ carrier sheet (Mylar) + 0.120″ compressible backing material (Roger

R-Bak)

* floating mount: the 0.030″ carrier sheet was only attached to the 0.120″ compressible backing material by a stitched lead edge.

The drawings of plate package setup are shown in figure 12. The printing test plates were manufactured and checked for quality by Mark/Trece Inc., Baltimore, MD. The quality proof documents of the printing test plates are shown in Appendix C.

3.1.3 Printing Inks

In order to print the three-color process work, transparent inks were required. The inks used for printing in this experiment were yellow, magenta and cyan color. They were sponsored from Sun Chemical Corporation, Philadelphia, PA. The specifications of the printing inks were as follows:

Yellow ink:

Product name	:	PPG20041C/P
Product description	:	CCLV POST PRINT PRO YELLOW
Product category	:	Water Flexo Corrugated Ink
Viscosity	:	22 seconds (number 2 Zahn cup)

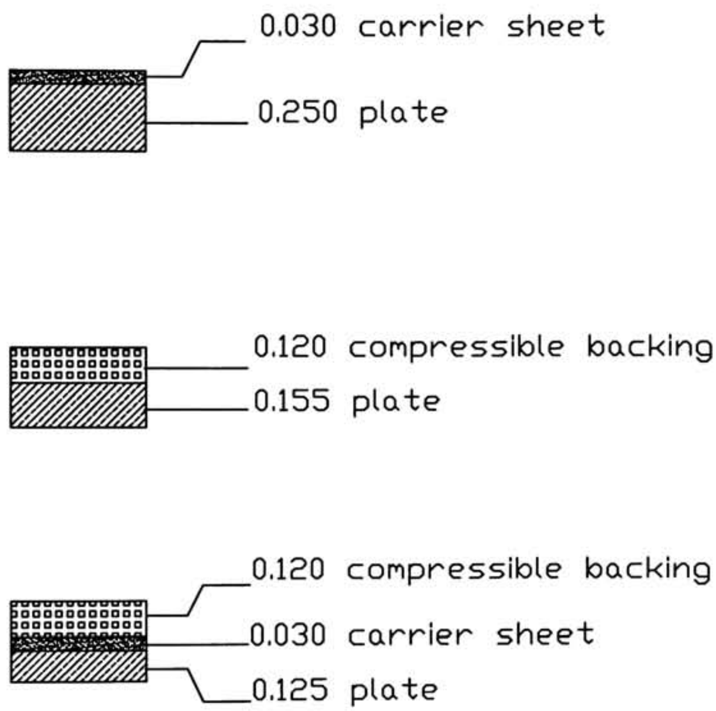


Figure 12 : The Plate package Setup

Magenta ink:

Product name	:	PPG40042C/P
Product description	:	CCLV POST PRINT PRO MAGENTA
Product category	:	Water Flexo Corrugated Ink
Viscosity	:	22 seconds (number 2 Zahn cup)

Cyan ink:

Product name	:	PPG50043C/P
Product description	:	CCLV POST PRINT PRO CYAN
Product category	:	Water Flexo Corrugated Ink
Viscosity	:	22 seconds (number 2 Zahn cup)

3.2 Graphic Design.

The sample containers for this experiment were printed on all four panels. The printing area coverage for each panel was designed to be one inch away from the edges of the panel as McCaughey (1995) recommended. Thus, the area of graphic printed on both side panels of sample containers was 12″ x 7″ (LxW) and, the area of graphics printed on both end panels of sample containers was 8″ x 7″ (LxW). These resulted approximately sixty-five percent of printed-area coverage on four printed panels of corrugated containers.

The graphics printed on sample containers included the sample identification number, impression gauge and three-color process halftone graphics. The sample identification number

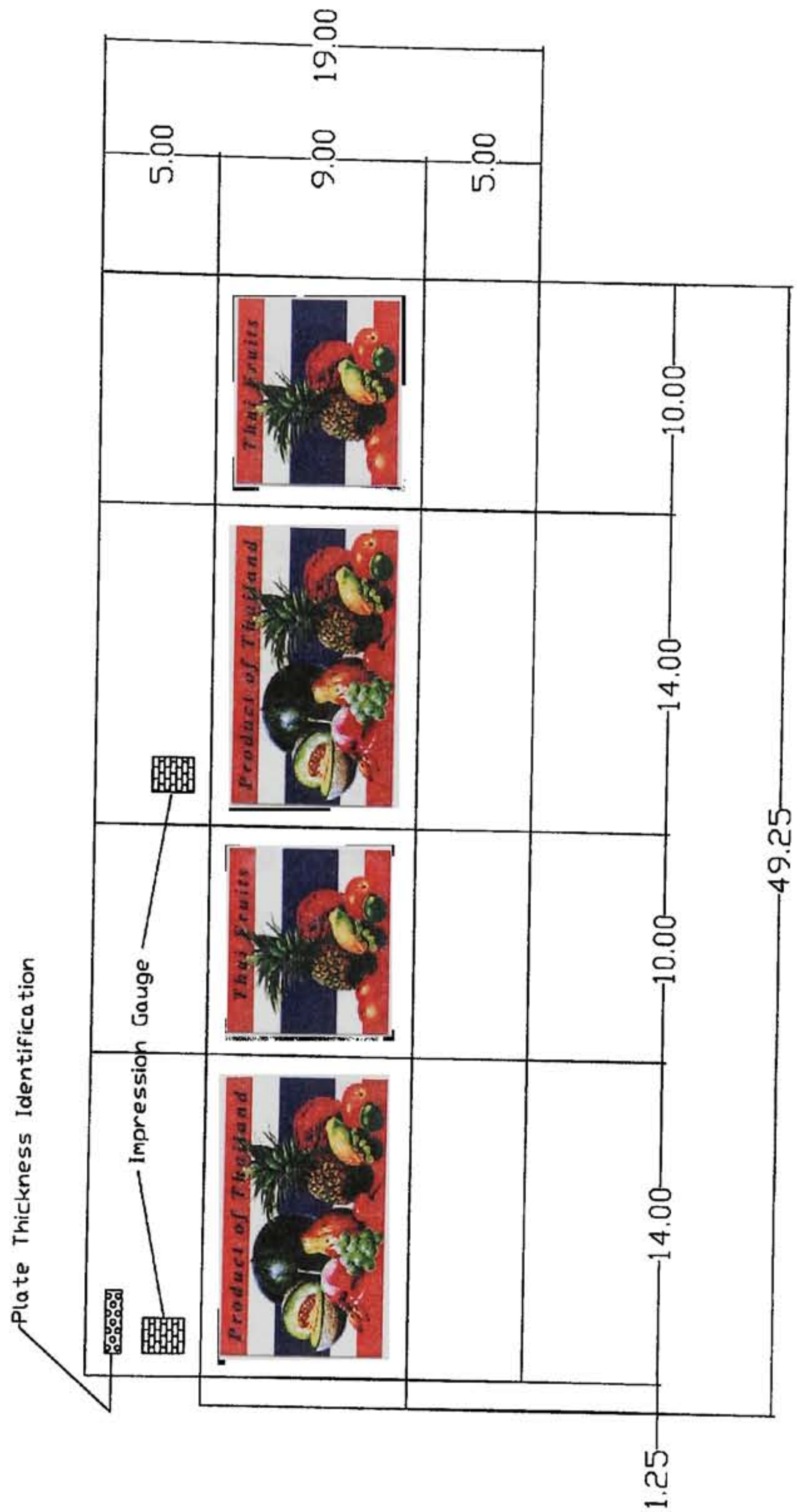


Figure 13 : Printing Layout

was designed to be printed on the flaps of sample containers to help classify samples being produced. The impression gauge was used to help control the printing impression while the sample containers were reproducing.

The graphics were designed based on the three-color process principle. According to the principle, full color graphics can be reproduced by overprinting three process colors. The three-color-process technique was selected for this project since it is the fast growing technique that corrugated graphic designers have been currently asked to respond for designing high quality graphic on postprint corrugated containers (McCaughey, 1995). The graphics were manipulated by the Adobe Photoshop version 4.0 at the School of Printing, RIT. The graphics were color separated and converted into the 45 line screen halftone dot information by Mark/Trece Inc. Baltimore, MD. The printed layout is shown in Figure 13.

3.3 Manufacture and Printing of Containers

The sample containers were manufactured based on the combination of three varied factors: A (different plate thickness and mounting materials), B (number of colors being printed) and C (the printing impression). Each factor was divided into different types and levels. The details were the following:

Factor A

Type a1 = 0.250″ plate mounted on Mylar

Type a2 = 0.155″ plate mounted on R-Bak

Type a3 = 0.125″ plate mounted on Mylar and R-Bak

Factor B

Type b1 = one color printing

Type b2 = three color printing

Factor C

Level 1 = heavy printing impression

Level 2 = light printing impression

The combination of these three factors created a total of 12 sample treatments. The presentation of these treatments is shown in Table 3. Also, the unprinted sample containers were manufactured to represent the preprint containers.

Table 3 : The Combination of Sample Treatments

Sample Treatment	combination
1	0.250″ plate/1color/heavy pip (a1b1c1)
2	0.250″ plate/1color/light pip (a1b1c2)
3	0.250″ plate/3color/heavy pip (a1b2c1)
4	0.250″ plate/3color/light pip (a1b2c2)
5	0.155″ plate/1color/heavy pip (a2b1c1)
6	0.155″ plate/1color/light pip (a2b1c2)
7	0.155″ plate/3color/heavy pip (a2b2c1)
8	0.155″ plate/3color/light pip (a2b2c2)
9	0.125″ plate/1color/heavy pip (a3b1c1)
10	0.125″ plate/1color/light pip (a3b1c2)
11	0.125″ plate/3color/heavy pip (a3b2c1)
12	0.125″ plate/3color/light pip (a3b2c2)

"pip" means printing impression

The sample containers were manufactured by the RDA Container, Rochester, NY. The flexo folder-gluer used for production was a three-color McKinley flexo press. (serial number 10789). Its printing stations were equipped with 180-line screen, ceramic anilox rolls and plastic doctor blades.

While the sample containers were manufacturing, the flexo folder-gluer ran at speed of 2,000 containers per hour. The feed roll pressure was set at 75 unit. The sequence of ink setup was yellow, magenta and cyan respectively. The schematic of machine setup for this experiment is shown in Figure 14.

All sample containers were run on the same day. The production of fifteen containers was run for each sample treatment. The production of the sample containers was started with 0.250″ plate, followed by 0.155″plate and 0.125″ plate respectively. Within each plate thickness, the one color containers were run with the lighter printing impression first, then run with the heavier printing impression. After that, three-color containers were run with the same sequence of printing impression. The unprinted containers were run after all printed containers were made. When the unprinted containers were manufactured, all the printing plates were taken off from printing cylinder, and the printing impressions were removed. The production order of sample containers is shown in Table 4.

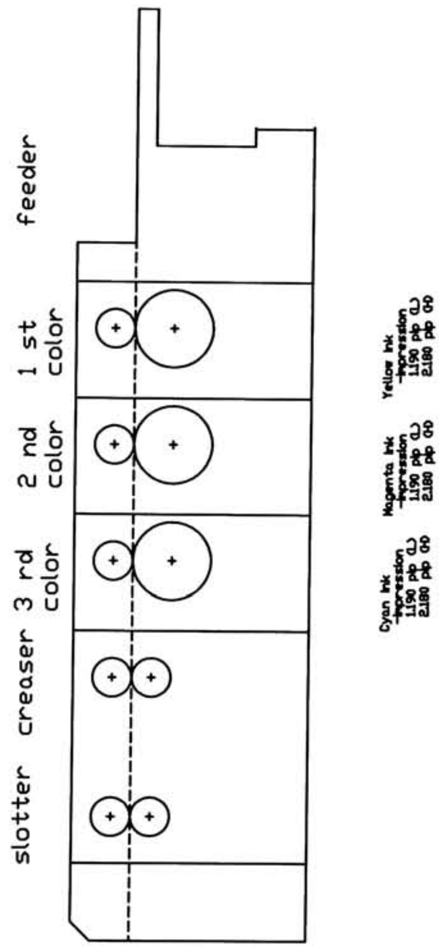


Figure 14 : Flexo Floder-Gluer Setup

Table 4 : The Production Order of Sample Containers

production order	sample treatment	amount of production (boxes)
1	a1b1c2	15
2	a1b1c1	15
3	a1b2c2	15
4	a1b2c1	15
5	a2b1c2	15
6	a2b1c1	15
7	a2b2c2	15
8	a2b2c1	15
9	a3b1c2	15
10	a3b1c1	15
11	a3b2c2	15
12	a3b2c1	15
13	unprinted	15

There were a total of thirteen bundles of sample containers. Each bundle of fifteen containers was individually strapped across the flaps with plastic strapping to separate the bundles and to minimize damages to the samples. All the containers were carefully shipped from the RDA Container to the Packaging Science Department at RIT. After arrived at RIT, each bundle was moved by hand to the precondition room.

3.4 Test Method

3.4.1 Preconditioning and Conditioning

All samples were preconditioned and conditioned according to ASTM Standard D 685-93 (Standard Practice for Conditioning Paper and Paper Products for Testing). ASTM Standard D 685-93 recommended that containers made from a paper product should be preconditioned at 10 to 35 % relative humidity and 22° to 40°C. The conditioning atmosphere should take place at 50 +/- 2% relative humidity and 23 +/- 1°C

The knocked-down sample containers were preconditioned at the Packaging Material Lab of Packaging Science Department, RIT., for forty-eight hours. The actual atmosphere in the preconditioned room was approximately 24% relative humidity and 22°C during that forty-eight hours.

These containers were then moved into the 400-700 CFM Climate-Lab, the climatic chamber, for 48-hour conditioning. The chamber's serial number is AA-5474. The atmosphere in the climatic chamber during the conditioning period was set at 50% relative humidity and 23°C.

3.4.2 Testing Procedure

The compression test of sample containers was conducted at the Packaging Dynamic Lab of the Packaging Science Department, RIT. All compression tests were made under standard conditions of 50% relative humidity and 23°C according to the ASTM Standard D685-93.

All Compression tests were made on the LANSMONT 122-15K Container Compression Test System (CCTS) which was designed for compression testing of packages, components and materials in accordance with ASTM D642, D4169, ISO 2874, 2872 and TAPPI T804. The compression was applied by means of a hydraulic cylinder. Force was measure by a strain-gauge load cell, and deflection was measured by a precision linear potentiometer. The CCTS was equipped with load platens which were operated in the fixed mode.

The compression machine was set according to ASTM Standard D642-90 (Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads). The set-up configuration of the CCTS compression machine is shown in Table 5.

Before the compression test was performed, the sample containers were moved from the climatic chamber one bundle at a time. Containers were set up and sealed with two-inch wide transparent, pressure sensitive tape, applied over the seams of the containers, continuing at least two inches onto the containers' ends. The closure method was in accordance with the ASTM Standard D1974-92 (Standard Practice for Methods of Closing, Sealing, and Reinforcing Fiberboard Shipping Containers). and is shown in Figure 15.

During the test, sample containers were placed between two platens of the compression machine in the top to bottom direction. Sample containers were always positioned with the manufacturer's joint to the left, faced the operator when he was at the control of the machine. Guide tapes were placed on the lower platen to ensure that samples were positioned uniformly all over the tests. The compression testing of sample containers is shown in Figure 16.

Table 5 : The Setup Configuration of the Compression Machine

Configuration	setup status
Preload for deflection auto zero	50.00 lbs.
Yield detection percentage	20.00 %
Stop force	10000.00 lbs.
Stop deflection	1.00 inch
Test velocity	0.05 inch/min
Auto sample number	ON
Auto log on test completion	Auto
Overlay auto test copy interval	Every 1
Auto print test interval	OFF

For each of the thirteen sample treatments, the average top to bottom compression strength value was based on ten replicates. All data referred to the maximum yield force at the yield force deflection. The failures of sample containers after being compressed were investigated. Testing was completed in two consecutive days.

After compression data was collected, Analysis of variance (ANOVA) on this data was performed. Because there may be some variations in quality among corrugated containers eventhough they were fabricated from the same production run, the Randomized Complete Block (RCB) statistical design was selected to performing analysis. This statistical method was selected since it allowed operator to analyze whether there was any variations among each sample being tested. Then the Least Significant Difference (LSD) method was used to perform inspection of mean differences.

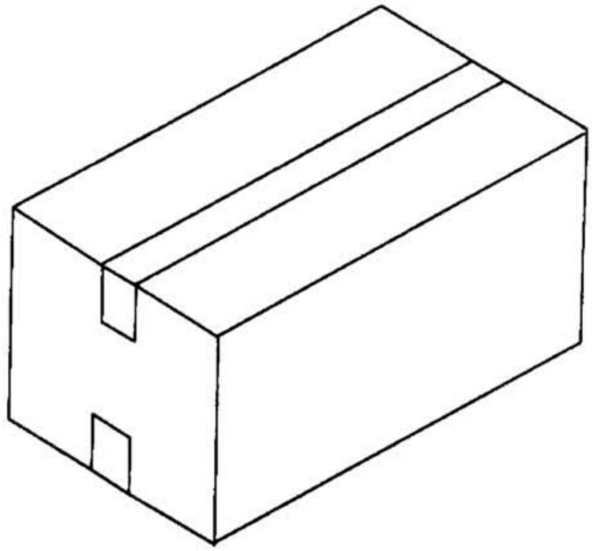


Figure 15 : The Closure Method

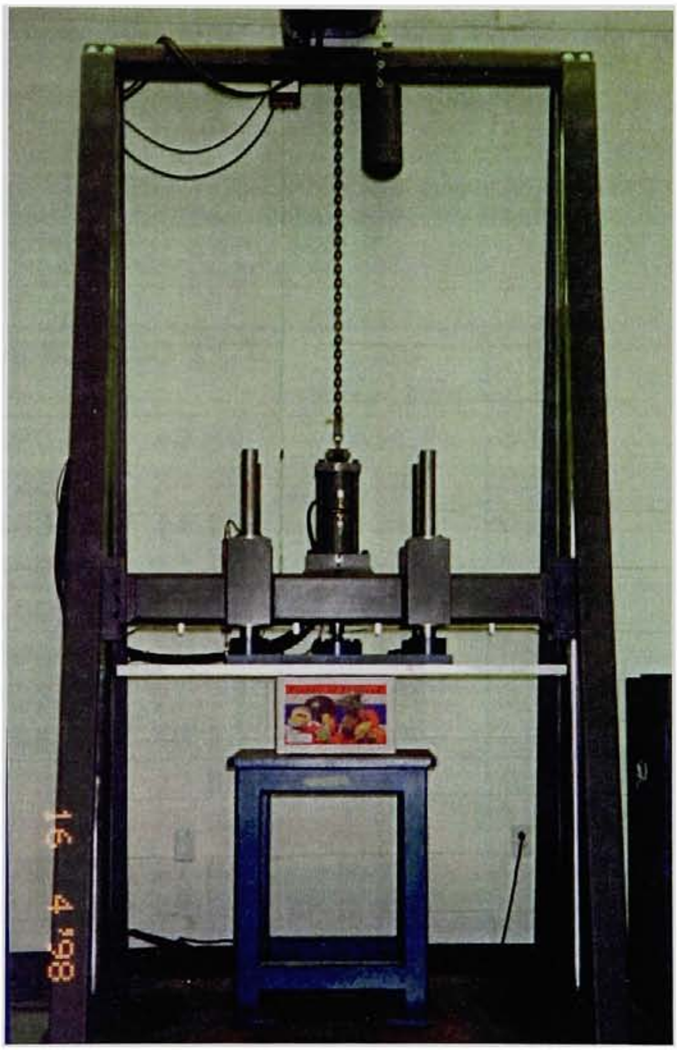


Figure 16 : Compression Testing of Sample Container

4.0 DATA AND RESULTS

In this study, approximately 200 RSC style containers were manufactured using different printing materials and printing condition. The top to bottom compression strength of the sample containers were investigated using the CCTS compression machine. The resultant data is shown in Table 6. Also, the average compression data of each sample treatment is graphically shown in Figure 17. The calculation of the average BCT values and deflection values can be referenced to Table A-1 to A-7.

Table 6 : The Top to Bottom Compression Result

Treatments	Ave BCT	SD (BCT)	Load deflection	SD (Defl)
a1b1c1	520.1	42.50	0.319	0.015
a1b1c2	522.0	24.50	0.309	0.024
a1b2c1	463.3	44.91	0.312	0.050
a1b2c2	468.2	53.79	0.336	0.034
a2b1c1	600.2	26.72	0.260	0.038
a2b1c2	594.6	18.39	0.241	0.024
a2b2c1	603.1	37.24	0.285	0.065
a2b2c2	585.1	46.76	0.300	0.031
a3b1c1	579.0	32.62	0.271	0.042
a3b1c2	578.0	25.04	0.243	0.034
a3b2c1	628.4	27.69	0.264	0.025
a3b2c2	599.4	41.36	0.320	0.044
unprinted	609.1	8.98	0.293	0.010

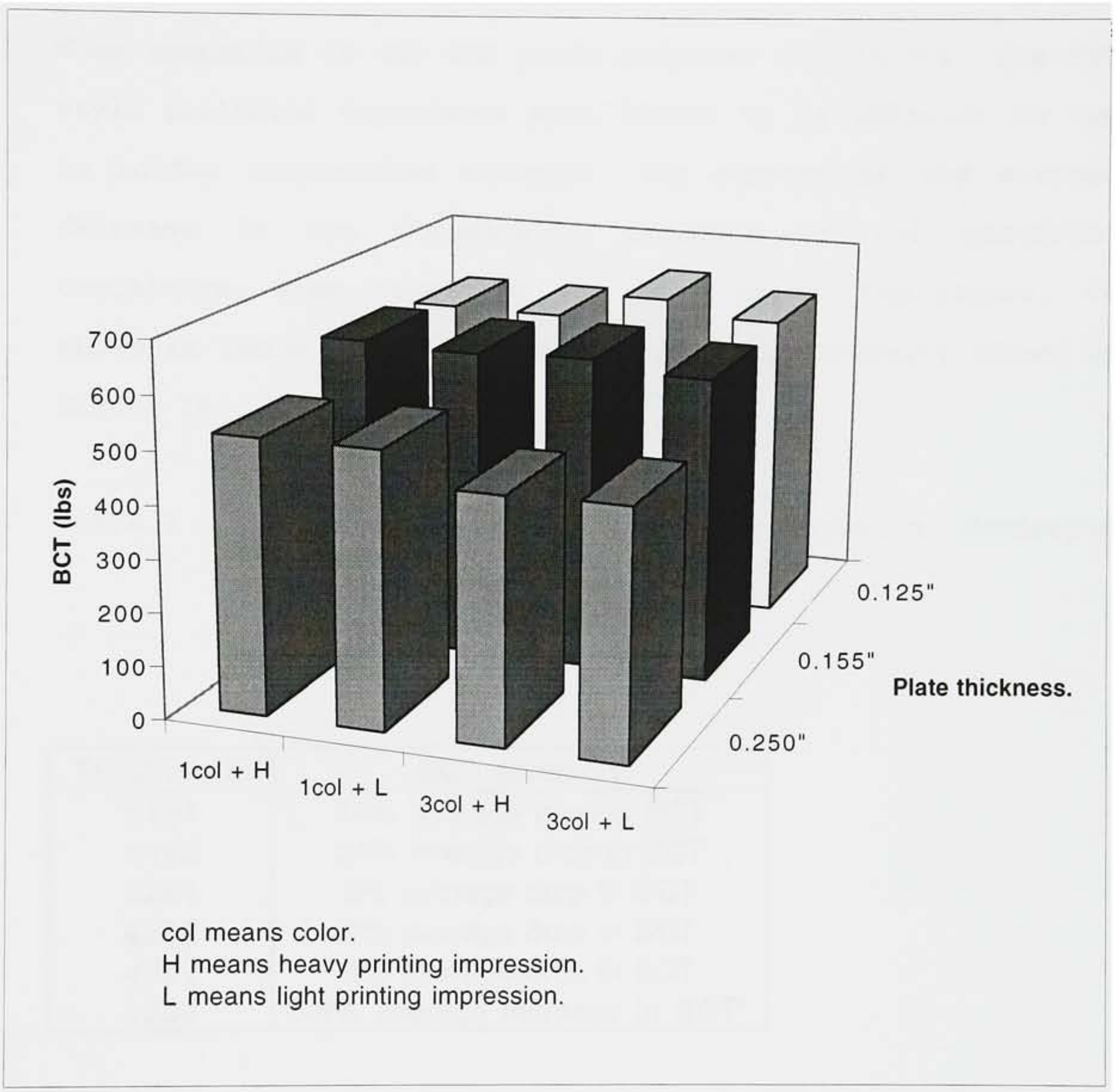


Figure 17 : The Average Compression Strength of each Sample Treatment

4.1 The Compression Strength Comparison of Preprint and Postprint Containers

When comparing to the RSC style preprint containers, the RSC style postprint containers were likely to be inferior in top to bottom compression strength. The summary of the average decrease in the compression strength of the postprint containers, when comparing to the preprint containers, is shown in Table 7. The summary is, also, graphically shown in Figure 18.

Table 7 : The Average Drop in Compression Strength, Comparing of Postprint and Preprint.

Treatments	BCT summary
a1b1	14% average drop in BCT
a1b2	24% average drop in BCT
a2b1	2% average drop in BCT
a2b2	2% average drop in BCT
a3b1	5% average drop in BCT
a3b2	0.8% average increase in BCT*

* An error occurred during the production of this sample.

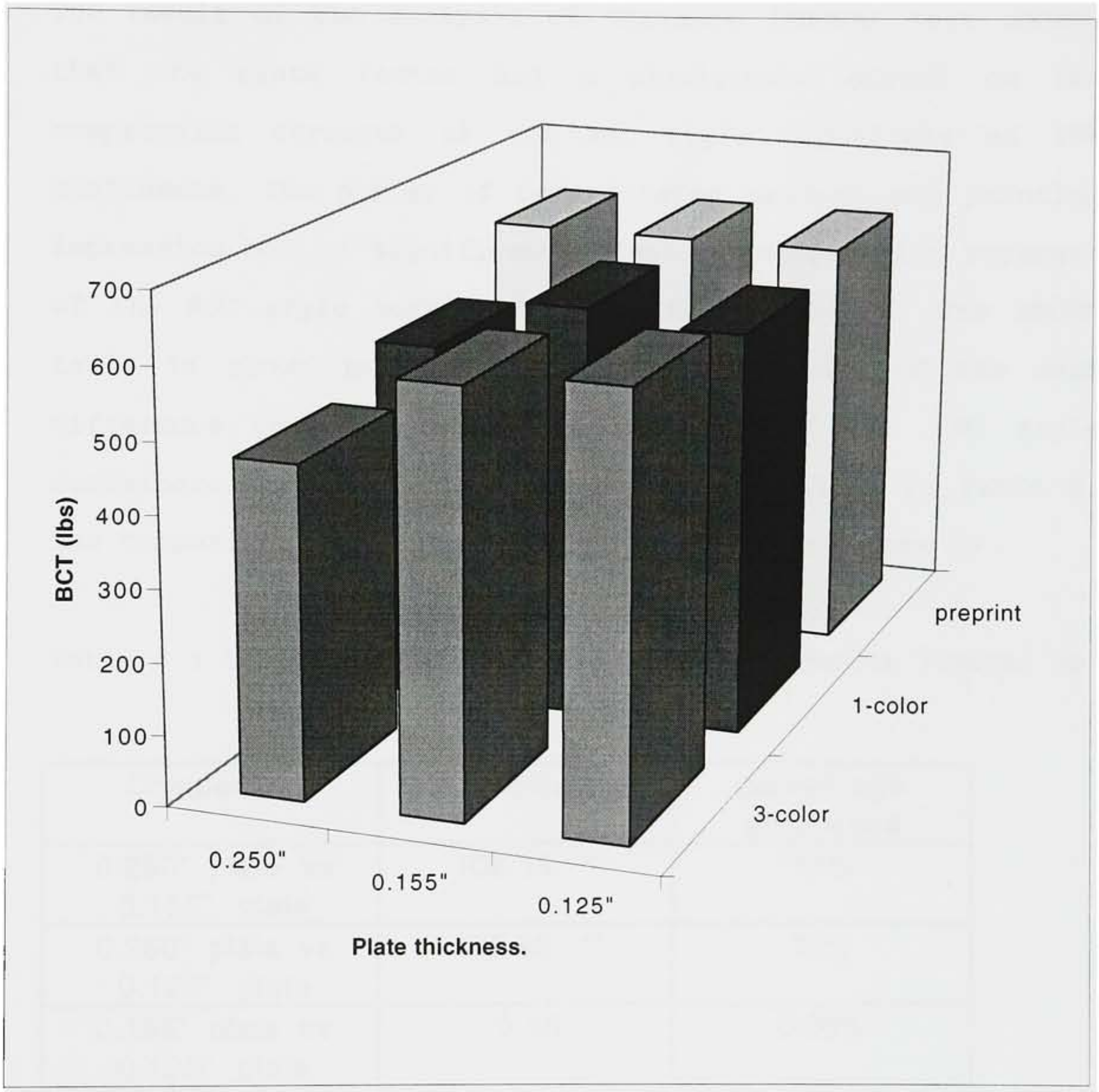


Figure 18 : Compression Strength Comparison of preprint and postprint

4.2 The Compression Strength Comparison of Containers Printed by Using Thick and Thin Plate Technology

The result of the Analysis of Variance (ANOVA) test showed that the plate factor had a significant effect on the compression strength of the RSC style containers at 99% confidence. The number of colors being printed and printing impression had no significant effect on compression strength of the RSC style corrugated shipping containers. The ANOVA table is shown in Table B-1. The comparisons of the mean difference on the compression strength of the RSC style containers, based on the plate factor, are shown in Table 8. The comparisons are also graphically shown in Figure 19.

Table 8 : The Comparison Based on the Plate Factor (Factor A)

Comparison	Mean difference	percentage difference
0.250" plate vs 0.155" plate	102.35 **	17%
0.250" plate vs 0.125" plate	102.80 **	17%
0.155" plate vs 0.125" plate	0.45	0.08%

** means that there was a significant difference at 99 % confidence.

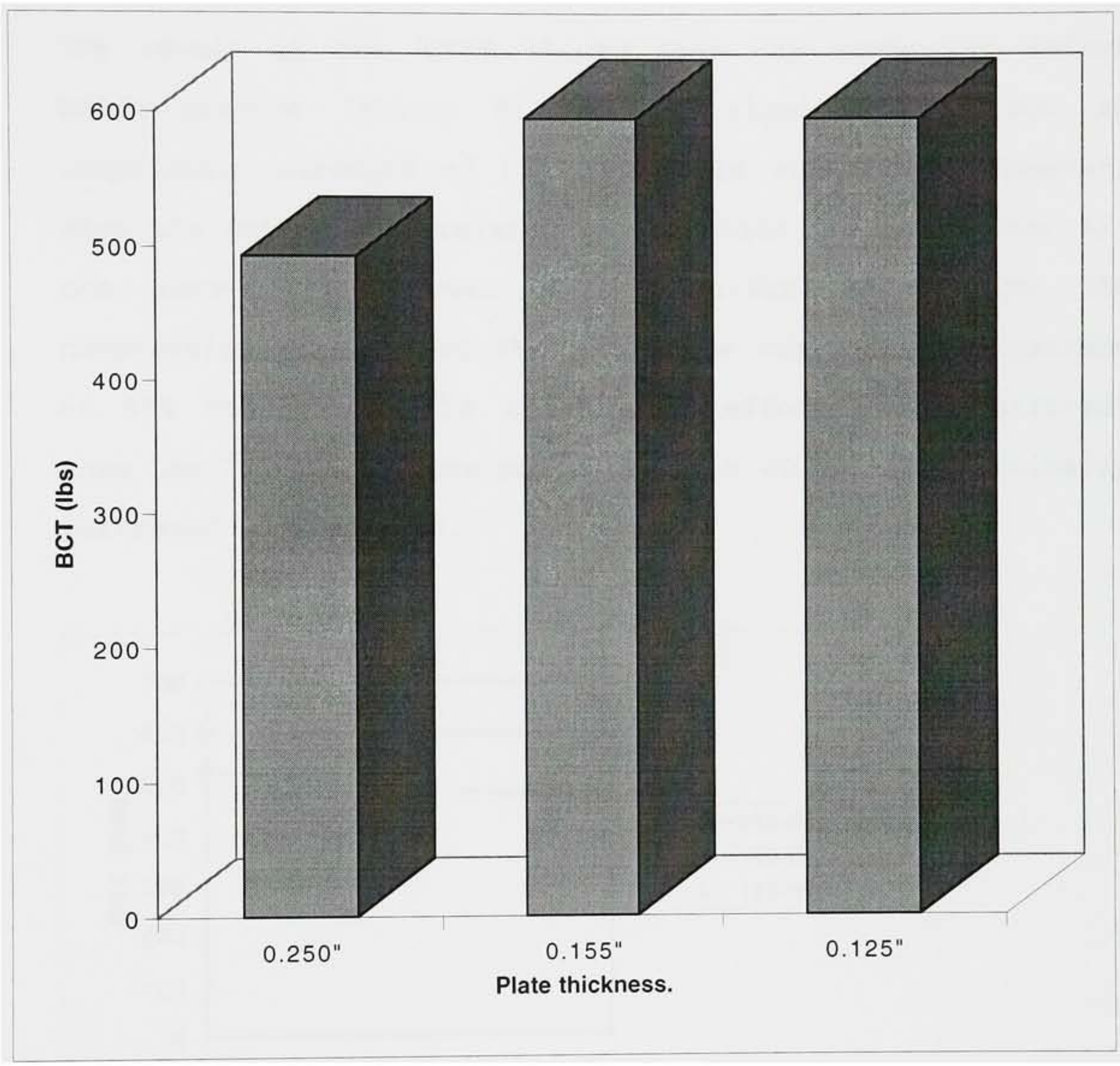


Figure 19 : Comparison of Compression Strength based on Plate Thickness

4.3 The Compression Strength Comparison of Containers Printed with One Color and Three Colors

The result of the ANOVA showed that the number of colors being printed (factor B) had no significant effect on compression strength of the RSC style containers. However, when the factor B correlated to the plate factor (Factor A), the correlation showed a significant effect on the compression strength of the RSC style corrugated containers at 99% confidence. The correlation effect was significant when the 250-thick plate was used. This effect is graphically portrayed in Figure 20.

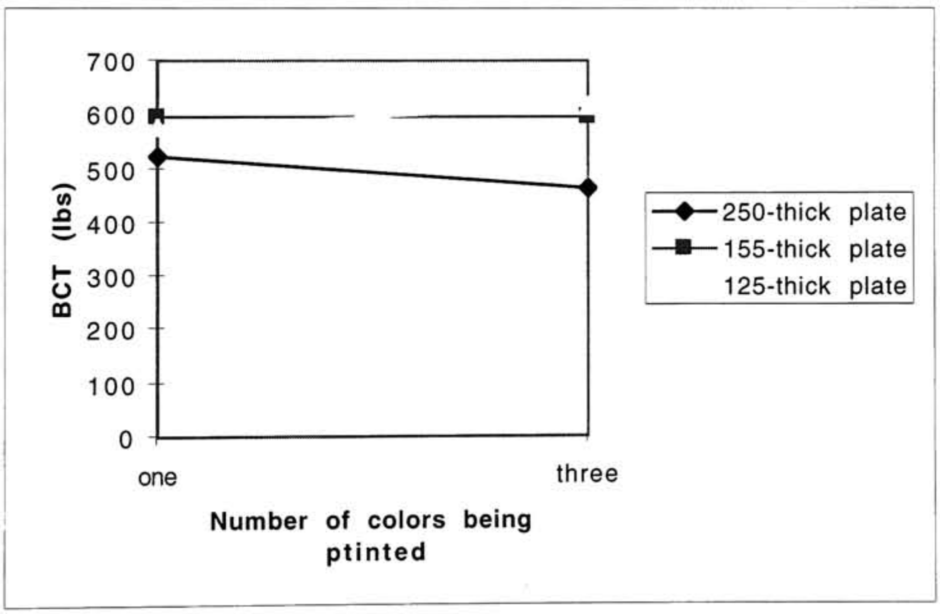


Figure 20 : The Interaction Effect between Factor A and Factor B

4.4 Discussion

The use of different printing plate technology, thick and thin, had a different effect on the compression strength of the RSC style containers. The results demonstrated that using the new thin plate technology to print high quality graphics on the RSC style containers could save their compression strength up to 17% when compared to the use of the conventionally thick plate.

A comparison of using a 0.155″-thick plate and a 0.125″-thick plate revealed no significantly different effect on the compression strength of the RSC style containers. However, using a 0.125″-thick plate to print graphics on corrugated containers had the advantage of yielding a higher printing quality. Furthermore, a 0.125″-thick plate provides better uniformity in thickness than a 0.155″-thick plate does.

With a conventionally thick plate to directly apply three-color process halftone graphics on corrugated containers, the result showed dramatic reduction in the compression strength of the RSC style containers, compared to the preprint containers. In contrast to the conventionally thick plate, using both of the thin plates showed only a slight reduction in compression strength, compared to the preprint containers.

Due to the compressible backing material used in the new thin plate technology, The compression strength of the printed RSC style containers was significantly maintained. The compressible backing material acted as a shock absorber between the printing plate and the impression cylinder as well as absorbing almost all of the impression forces applied at the printing stations. As a result, the possibility of corrugated boards' crush due to the printing process was reduced and the strength of the finished container was maintained.

According to Peleg (1985), besides the maximum compression force on the deflection curve, another important point in assessing the container's performance is the compression force at the critical deflection. The force at the critical deflection indicates performance at normal stacking loads without unacceptable damage to the product. Usually, the container without an internal divider has a critical deflection corresponding to approximately 70% of yield deflection.

When the deflection curve and the yield deflection data of the tested samples were examined, the results revealed that containers printed by using conventionally thick plate had a flat curve and a maximum yield deflection at 0.32 inch. Differently, containers printed by using the thin plate had a steep curve and a maximum yield deflection of 0.27 inch. As a result, a container with a less head space would be needed when printing with the thin plate technology. A reduced height would result in less material used per box and a material saving.

The statistical analysis demonstrated that the number of colors being printed alone had no significant effect on the compression strength of the printed containers. However, when that factor was correlated to the plate factor, the correlation had a significant effect on the compression strength of printed containers. This correlation effect was significant when the conventionally thick plate was used.

When the containers were printed using the conventionally thick plate, a trend showed a significant drop in the containers' compression strength when more colors were printed. The resultant data showed approximately 11% of the reduction in BCT when comparing the effect of one-color printing to that of the three-color printing. Conversely, the compression strengths of the containers, which were printed with one color and three colors by using the thin plate, were almost the same.

These occurrences can be explained in relation to the printing impression applied on corrugated boards, causing a specific number of flute damages. As the corrugated boards ran through each printing station, these damages added up causing a reduction in the strength of the finished containers. With the new thin plate technology, the compressible backing material absorbed much of the add-up impression force, resulted in the reduction of flute damages and the maintaining of the finished containers' compression strength. In contrast to that technology, there was no compressible backing material to absorb the add-up impression force in the traditional plate technology. As a result, there was a dramatic decrease in the containers' compression strength when more colors were printed using traditional plate technology.

The corrugated boards were physically examined after being printed with one color and three colors. The result of the examination showed that the damages due to the 1-color printing and the 3-color printing were different. The flute crowns of the corrugated board printed with three colors were likely to be damaged on both sides, outer and inner, while the flute crowns of the corrugated board printed with one color were damaged only on the printed side. The fluting damages are shown in Figure 21.

Maltenfort (1996) identified that there were many types of failures that occur after the containers were compression tested. The failure was identified as compression failure when the outside and inside of the corrugated board were both wrinkle after being compression tested. The compression

Printed liner

Inner liner

One-color printed corrugated board

Printed liner

Inner liner

Three-color printed corrugated board

Figure 21 : The Fluting Damage after Printing

failure was the normal type of failure that usually occurred. The failure was identified as bending failure when only one liner, either outer or inner, was wrinkled. The bending failure usually occurred when there was an unbalanced strength between the outer (printed) and the inner side of the corrugated board.

After being compressed, the containers printed with three colors were likely to have the compression failure at the corners and bending failure all across the side panels while the containers printed with one color had only compression failure at the corners. This occurrence happened because printing with more colors weakened the corrugated board especially the printed side. This resulted in the unbalanced strength between both sides of the corrugated board causing the bending failure. The compression failure and bending failure are shown in Figure 22 and 23.

Standard deviations of the BCT data between the 1-color printed containers and the 3-color printed containers showed a big difference. The average BCT data's standard deviation of the 1-color printed containers was 28.3, while that of the 3-color printed containers was 42.0. This data demonstrated that the degree of scatter increased as the number of colors being printed increased. This can be explained that the more color being printed, the more difficult it became to

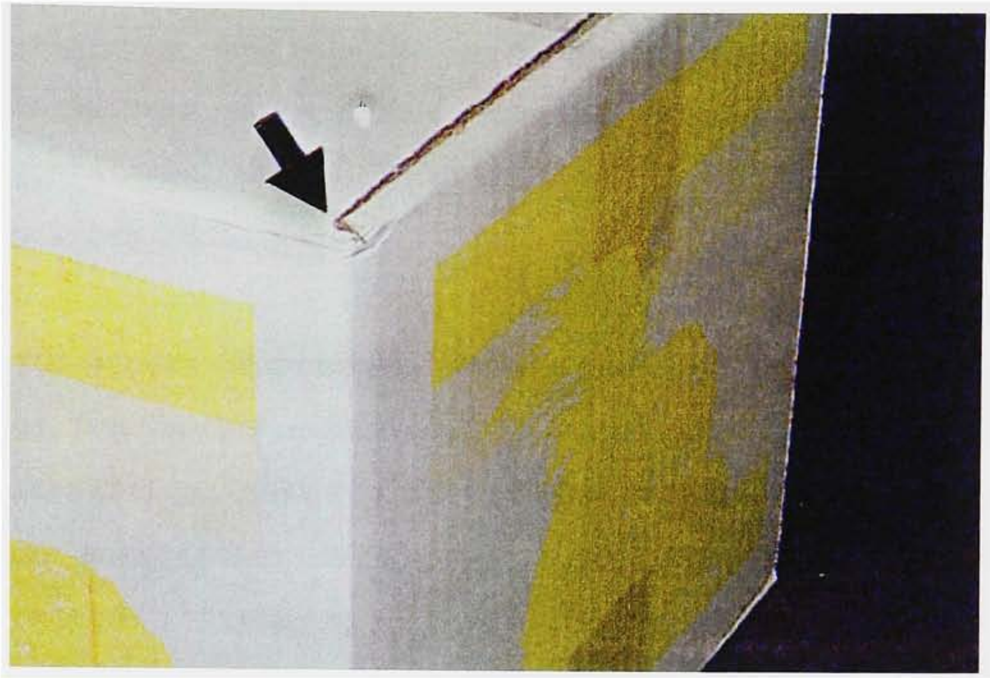


Figure 22 : Compression Failure

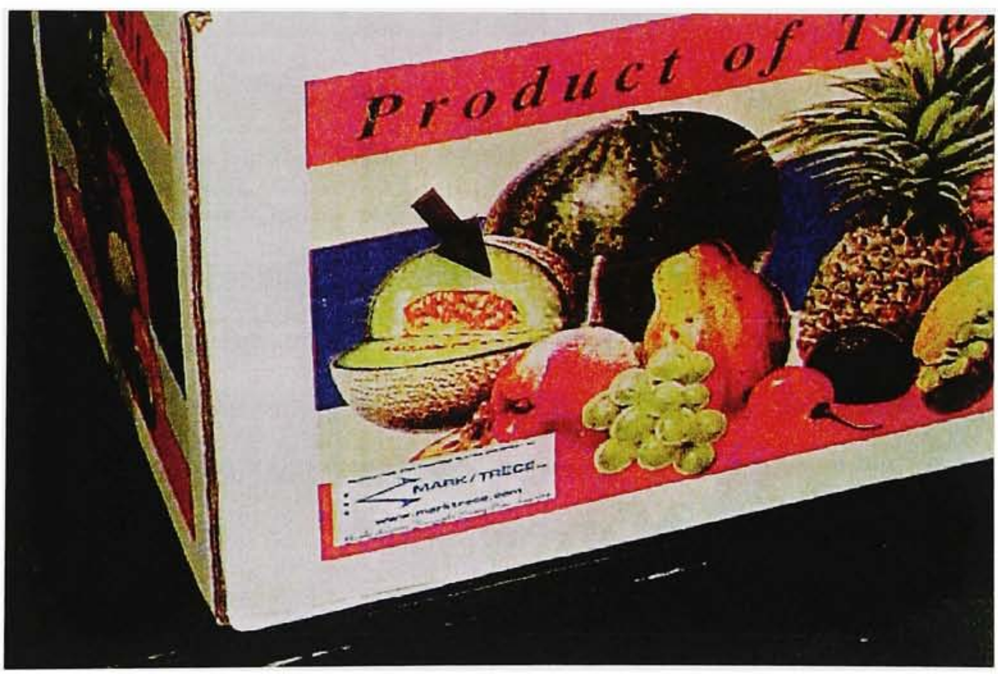


Figure 23 : Bending Failure

uniformly control the performance quality of the printed containers. As a result, the BCT data of the 3-color printed containers showed more scatter than that of the 1-color printed containers.

The effect of printing impression on the compression strength of corrugated containers was studied as well. However, the statistical analysis showed that the printing impression had no significant effect on the compression strength of the printed containers.

Due to some problems associated in the production process of the a3b2c1 samples, the data collected during the compression testing was higher than usual. This resulted in slightly elevated average data for this sample treatment.

The flying technique used to mount the 0.125″-thick plate caused a slight problem. Because the carrier sheet and compressible backing material were attached only on the top by a lead edge, the compressible backing material bounced the printing plate during the printing process, causing excess printing on non-printed areas. Operators had to stop the machine and to staple the carrier sheet and compressible backing material together. This resulted in longer machine set-up time.

5.0 CONCLUSIONS

Using the conventional plate technology to apply high quality graphics on the RSC style containers causes a notable reduction in containers' compression strength. With the conventional plate technology, printing more colors on corrugated containers also resulted in a significant reduction of the containers' compression strength.

The new thin plate technology is a very useful tool for box manufacturers when they have to manufacture the containers that required both the protective strength and the printing quality. The compressible backing material used in thin plate technology helped maintain the containers' compression strength and helped improve the printing quality. Using the compressible backing material in the thin plate technology also allowed box manufacturers to print more colors on containers without significantly decreasing their compression strength, even when printed with a large surface area and on all four panels.

The thin plate technology is also a very useful tool for the postprint industry to rival with the preprint industry. The compression strength of postprinting containers, which were printed by using the thin plate technology, was proven to be only a little less than those of preprinting containers. At the same time, the printing quality of postprinting containers has continuously improved.

6. RECOMMENDATIONS

The compression strength of the RSC style containers could be significantly reduced by the application of critical graphic designs which included: printing with many colors, high print coverage, printing on many panels, and printing over the edges or the corners. In this research, the sample containers were designed to be printed with a critical design- a high print coverage (65%) containing three colors and printed on all four panels. However, the research indicated that using the thin plate technology could maintain the compression strength of the printed containers although they were printed with a critical graphic design. Since there was a trend to print the RSC style containers with more critical graphic, such as 4 to 6 color graphics, the future research could look at the effect of printing more critical graphic designs with the use of thin plate technology

In addition to the advantage of maintaining the compression strength of the corrugated containers, the thin plate technology improved the printing quality as well. Bar code printed on corrugated board has always had the problem of poor scanability because of its low print quality. Thin plate technology could be a new solution for improving bar codes printing on corrugated containers. Therefore, further study is recommended in the area of improving bar codes printing on corrugated board with the thin plate technology.

APPENDIX A

Table A-1 : The BCT Data of Containers Printed by 0.250"-Thick Plate

sample	a1b1c1	a1b1c2	a1b2c1	a1b2c2
1	572.8	516.2	466.3	520.0
2	527.6	509.0	432.1	401.0
3	454.4	537.2	442.3	420.0
4	573.0	490.1	499.0	500.5
5	470.3	538.1	470.0	441.6
6	493.7	516.5	505.1	505.0
7	480.7	543.8	404.4	539.5
8	537.0	477.0	470.0	397.4
9	544.1	543.6	542.8	488.8
10	547.2	548.4	401.4	***
average	**520.1**	**522.0**	**463.3**	**468.2**
max	573.0	548.4	542.8	539.5
min	454.4	477.0	401.4	397.4
SD	42.5	24.5	44.9	53.8

Table A-2 : The Deflection Data of Containers Printed by 0.250"-Thick Plate

sample	a1b1c1	a1b1c2	a1b2c1	a1b2c2
1	0.30	0.33	0.24	0.35
2	0.30	0.32	0.29	0.31
3	0.33	0.29	0.31	0.36
4	0.32	0.28	0.32	0.35
5	0.34	0.30	0.31	0.40
6	0.32	0.32	0.36	0.30
7	0.32	0.35	0.40	0.33
8	0.34	0.28	0.27	0.33
9	0.32	0.29	0.36	0.29
10	0.30	0.33	0.26	***
average	**0.319**	**0.309**	**0.312**	**0.336**
max	0.34	0.35	0.40	0.40
min	0.30	0.28	0.24	0.29
SD	0.015	0.024	0.050	0.034

*** means that there was an error in data

Table A-3 : The BCT Data of Containers Printed by 0.155"-Thicl Plate

sample	a2b1c1	a2b1c2	a2b2c1	a2b2c2
1	548.1	607.3	619.3	620.0
2	595.3	581.2	552.2	648.1
3	629.5	562.3	656.9	518.0
4	611.5	608.4	577.6	585.7
5	610.4	590.0	628.3	534.1
6	564.8	622.8	630.0	574.8
7	585.7	590.6	560.0	635.8
8	617.2	596.5	***	573.0
9	626.0	575.5	574.6	533.2
10	613.6	611.0	628.9	628.4
average	**600.2**	**594.6**	**603.1**	**585.1**
max	629.5	622.8	656.9	648.1
min	548.1	562.3	552.2	518.0
SD	26.7	18.4	37.2	46.76

Table A-4 : The Deflection Data of Containers Printed by 0.155"-Thick Plate

sample	a2b1c1	a2b1c2	a2b2c1	a2b2c2
1	0.23	0.23	0.34	0.38
2	0.22	0.23	0.28	0.31
3	0.23	0.26	0.36	0.27
4	0.23	0.25	0.20	0.30
5	0.23	0.22	0.34	0.31
6	0.28	0.24	0.30	0.30
7	0.28	0.23	0.20	0.29
8	0.34	0.22	***	0.29
9	0.28	0.30	0.21	0.28
10	0.28	0.23	0.33	0.29
average	**0.260**	**0.241**	**0.285**	**0.30**
max	0.34	0.30	0.36	0.38
min	0.22	0.22	0.20	0.27
SD	0.038	0.024	0.065	0.031

*** means that there was an error in data

Table A-5 : The BCT Data of Containers Printed By 0.125"-Thick Plate

sample	a3b1c1	a3b1c2	a3b2c1	a3b2c2
1	581.3	530.0	639.1	579.0
2	567.9	565.0	602.0	550.0
3	621.9	580.0	632.7	***
4	638.9	610.0	613.0	570.0
5	567.6	612.0	596.0	670.0
6	542.1	550.0	641.8	585.0
7	570.0	575.0	611.3	586.0
8	564.6	586.0	685.8	570.0
9	536.4	585.0	608.7	645.0
10	599.6	587.0	653.5	640.0
average	**579.0**	**578.0**	**628.39**	**599.4**
max	638.9	612.0	685.8	670.0
min	536.4	530.0	596.0	550.0
SD	32.62	25.04	27.69	41.36

Table A-6 : The Deflection Data of Containers Printed by 0.125"-Thick Plate

sample	a3b1c1	a3b1c2	a3b2c1	a3b2c2
1	0.25	0.22	0.26	0.37
2	0.29	0.23	0.29	0.29
3	0.21	0.22	0.28	***
4	0.31	0.23	0.24	0.33
5	0.31	0.22	0.27	0.32
6	0.31	0.32	0.29	0.34
7	0.32	0.22	0.29	0.22
8	0.26	0.24	0.24	0.33
9	0.23	0.29	0.22	0.32
10	0.22	0.24	0.26	0.36
average	**0.271**	**0.243**	**0.264**	**0.320**
max	0.32	0.32	0.29	0.37
min	0.21	0.22	0.22	0.22
SD	0.042	0.034	0.025	0.044

*** means that there was an error in data

Table A-7 : The BCT and Deflection Data of Unprinted Containers

sample	BCT	deflection
1	617.2	0.29
2	617.0	0.29
3	614.3	0.30
4	599.7	0.28
5	596.5	0.29
6	610.0	0.31
average	**609.1**	**0.293**
max	617.2	0.31
min	596.5	0.28
SD	8.98	0.010

APPENDIX B

Table B-1 : ANOVA Table

Source of variation	d.f.	SS	MS	F
Replication (R)	(r-1) = 9	9983.76	1109.31	0.85
Treatment (T)	(t-1) = 11	329856.16	29986.92	23.00 *,**
A	(a-1) = 2	280567.37	140283.69	107.62 *,**
B	(b-1) = 1	1788.72	1788.72	1.37
C	(c-1) = 1	1832.23	1832.23	1.40
AB	(a-1) (b-1) = 2	41378.51	20689.25	15.87 *,**
AC	(a-1) (c-1) = 2	1932.48	966.24	0.74
BC	(b-1) (c-1) = 1	1162.52	1162.52	0.89
ABC	(a-1) (b-1) (c-1) = 2	1994.33	579.16	0.46
Errror (R xT)	(r-1) (t-1) = 99	129049.68	1303.53	
Total	tr-1 = 199	468889.60		

* means significant at 95% confidence.

** means significant at 99% confidence.

LSD 0.05 (plate) 16 lbs

LSD 0.01 (plate) 21 lbs

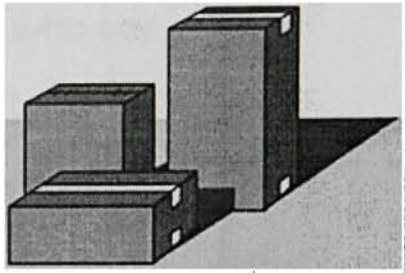
APPENDIX C

MARK/TRECE INC.

806 Race Road West
Baltimore, MD 21221

Quality Policy

MARK/TRECE, INC. IS DEDICATED TO THE ADVANCEMENT OF THE FLEXOGRAPHIC INDUSTRY BY PROVIDING THE HIGHEST QUALITY PRODUCTS AND SERVICES, WITH CONTINUAL IMPROVEMENT BASED UPON THE ISO-9002 MODEL REQUIREMENTS OF THE INTERNATIONAL STANDARDS ORGANIZATION. THE EMPLOYEES OF MARK/TRECE ARE DEDICATED TO THE BELIEF THAT OUR CUSTOMERS DESERVE NOTHING LESS THAN COMPLETE SATISFACTION.



YOUR QUALITY ASSURANCE SHEET

SALES/ORDER ENTRY Jim LD | [illegible]
- [x] WRITTEN INSTRUCTIONS CLEAR AND COMPLETE
- [x] REFERENCES LISTED

1 (REVISIONS) **GRAPHICS** Glen | B.G
- [x] CLEAN ATTRACTIVE GRAPHICS
- [x] CORRECT TYPE STYLES AND SPACING
- [x] CORRECT COPY AND SPELLING

NEGATIVE PREP Glen | B.G
- [ ] [x] CORRECT SIZES
- [ ] [x] ACCURATE VISIBLE CENTER LINES
- [ ] [x] PROPER ALLOWANCE FOR STRETCH
- [ ] [x] CORRECT COLOR BREAK AND REGISTRATION
- [ ] [x] ACCURATE BLEEDS AND TRAPS

PRINT CARD | NA
- [ ] CORRECT FORMAT
- [ ] CORRECT COPY

PLATE MATERIAL 125/155 67 | .250 .067
- [ ] LIQUID PHOTOPOLYMER
- [x] CYREL
- [ ] LASER ENGRAVED RUBBER
- [ ] HANDCUT SOFT RUBBER
- [ ] FLEXO

DIGITAL TAPE | [illegible]
- [x] CALIPER ACCURACY
- [x] PRINT SURFACE BLEMISH FREE
- [x] ACCURATE VISIBLE CENTER LINES

[illegible] **PREMOUNT** BARRY |
- [x] CORRECT CYLINDER SIZE
- [x] MOUNTED PER SPECIFICATIONS
- [x] CORRECT PLATE POSITIONING AND LAYOUT
- [x] PROPERLY CLEANED AND SEALED PLATES

SHIPPING | [illegible]
- [ ] SYMBOLOGY READ-OUT INCLUDED
- [ ] ACCURATE MINIATURES INCLUDED
- [x] PROOFS INCLUDED
- [x] REFERENCES AND COPIES RETURNED
- [ ] SPECIAL INSTRUCTIONS FOLLOWED
- [x] CORRECT AMOUNT OF PLATES

Digital watercolor Disks

You can reorder these plates by referring to the plate order number. If you have any questions, or comments, please call or write us. Thank you for your consideration of our products.

NAME OF JOB: RIT BOARD STRESS TEST PLATE ORDER NO.: 43347 DATE SHIPPED: 3-25-98

DOCUMENT # Q-1 (BALTIMORE) REV. 10/96

The enclosed plates have been verified with our

Flexographic Digital Micrometer

The tape provided tells you the following:

N - Number of Points Checked...... 13
MAX - Highest Point of Plates........ .2500
MIN - Lowest Point of Plates........ .2493
R - Actual Variation of Job........... .0007
$\bar{x}$ - Average Thickness................ .2496

This is one way in which Mark/Trēcé's Statistical Process Control program is working to provide our customers with a consistently high quality product.

```
*CLEAR*
  1  0.2493  I
  2  0.2493  I
  3  0.2498  I
  4  0.2495  I
  5  0.2493  I
  6  0.2498  I
  7  0.2498  I
  8  0.2499  I
  9  0.2494  I
 10  0.2499  I
 11  0.2500  I
 12  0.2499  I
 13  0.2497  I
PART NO. 43347
..................
DATE/TIME 3-25-98
..................
NAME
..................
*RESULT*
N              13
MAX   0.2500    I
MIN   0.2493    I
R     0.0007    I
x̄     0.249661  I
σn    0.000252  I
σn-1  0.000263  I
```

DOCUMENT # Q-? [BALTIMORE]

REV. 6-95

The enclosed plates have been verified with our

Flexographic Digital Micrometer

The tape provided tells you the following:

N - Number of Points Checked.......12
MAX - Highest Point of Plates.......1557
MIN - Lowest Point of Plates.......1547
R - Actual Variation of Job.........0004
$\bar{x}$ - Average Thickness..............1548

CLEAR

1	0.1550	I
2	0.1547	I
3	0.1548	I
4	0.1549	I
5	0.1549	I
6	0.1548	I
7	0.1551	I
8	0.1549	I
9	0.1549	I
10	0.1547	I
11	0.1550	I
12	0.1550	I

PART NO 43357
DATE 3-25-98
NAME

RESULT

N	12	
MAX	0.1551	I
MIN	0.1547	I
R	0.0004	I
$\bar{x}$	0.154891	I
σn	0.000118	I
$\sigma n-1$	0.000124	I

This is one way in which Mark/Trece's Statistical Process Control program is working to provide our customers with a consistently high quality product.

DOCUMENT # Q-2 (BALTIMORE) REV. 6-95

The enclosed plates have been verified with our

Flexographic Digital Micrometer

The tape provided tells you the following:

N - Number of Points Checked...... 12
MAX - Highest Point of Plates..... .1249
MIN - Lowest Point of Plates....... .1245
R - Actual Variation of Job.......... .0004
$\bar{x}$ - Average Thickness.................. .1247

This is one way in which Mark/Trece's Statistical Process Control program is working to provide our customers with a consistently high quality product.

CLEAR

1	0.1247	
2	0.1249	
3	0.1245	
4	0.1247	
5	0.1249	I
6	0.1246	I
7	0.1245	I
8	0.1248	I
9	0.1247	I
10	0.1249	I
11	0.1247	I
12	0.1249	I

PART NO. 43357
DATE TIME 3 25 98
NAME

RESULT

N	12	
MAX	0.1249	I
MIN	0.1245	
R	0.0004	
$\bar{x}$	0.124733	I
σ_n	0.000143	I
σ_{n-1}	0.000149	I

DOCUMENT # Q-? (BALTIMORE)

REV. 6-95

8.0 LIST OF REFERENCES

Arimond, John. and Koss, S.M. "Mechanical Characteristics of Corrugated Substrates", FLEXO, Vol. 20, No. 9, 1995.

ASTM "Selected ASTM Standards on Packaging", Philadelphia, PA., American Society for Testing and Materials, 1994.

Bakker, M. "The Wiley Encyclopedia of Packaging Technology", John Wiley & Son, Inc., 1986.

Bessen, A. Howard. "Design and Production of Corrugated Packaging and Displays", Plainview, New York, NY., Jelmar Publishing Co., Inc., 1990.

Carlson, A. David. "Corrugating Defect Terminology", Atlanta, GA., TAPPI PRESS, 1988.

Cuir, Jean-Pierre. "Graphic/Flexography", 1992 Corrugated Container Conference, 1992.

Cusdin, B. George. "Gaining Control of the Process for Corrugated Post-Print", 1994 International Corrugated Container Conference, 1994.

Cusdin, B. George. "What Plate Thickness Really Works Best?", FLEXO, Vol. 22, No. 3, 1997.

Diethorn, A. Gregory. "Full Control No Crush Feed System", 1996 International Corrugated Container Conference, 1996.

Elderd, N. Richards. "Package Printing", Plainview, New York, NY., Jelmar Publishing Co., Inc., 1993.

Eyre, R. Michael and Kaczor, A. Nancy. "The effect of Flexographic Printing on the Compression Strength of Corrugated Shipping Containers" Packaging Science Department, Rochester Institute of Technology, 1990.

Fibre Box Association. "Fibre Box Handbook", Rolling Meadows, IL. Fibre Box Association., 1992.

Flexographic Technical Association. "Flexography Principles and Practices, Fourth Edition", Foundation of Flexographic Technical Association., Inc., 1991.

Friedman, F. Walter and Kipnees, J. Jerome. "Distribution Packaging", Huntington, NY., Robert E. Krieger Publishing Company, 1977.

Jonson, Gunilla. "Corrugated Board Packaging", Leatherhead, UK., Pira International, 1993.

Kelly, John. "Post Printing on Corrugated Board", 1992 Corrugated Container Conference, 1992.

Koning, John. “Corrugated Crossroads”, Atlanta, GA., TAPPI PRESS, 1995.

Maltenfort, G. George. “Corrugated Shipping Containers An Engineering Approach”, Plainview, New York, NY., Jelmar Publishing Co., Inc., 1996.

Maltenfort, G. George. “Performance and Evaluation of Shipping Containers”, Plainview, New York, NY., Jelmar Publishing Co., Inc., 1989.

Markstrom, Hakan. “Testing Methods and Instruments for Corrugated Board”, Stockholm, Sweden, Lorentzen & Wettre, 1988.

Maynes, Leo. “Getting Maximum Benefit from Today’s Corrugated Box Finishing Machinery”, 1992 Corrugated Container Conference, 1992.

McCaughey, G. Donald. “Graphic Design for Corrugated Packaging”, Plainview, New York, NY., Jelmar Publishing Co., Inc., 1995.

Paine, F. A. “The Packaging User’s Handbook”, Bishopbriggs, Glasgow, Blackie Academic & Professional, an Imprint of Chapman & Hall, 1991.

Peleg, Kalman. "Produce, Packaging and Distribution", Westport, Connecticut, The Avi Publishing Co., Inc., 1985.

Pomerenka, Rick. "Printing Plates: How to Choose the Right One", Corrugated Post-Print Graphics for the Future, University of Wisconsin, Milwaukee, WI., 1997.

Reynolds, F. Larry. "Postprint and Preprint: Getting the Best from Both Worlds", 1992 Corrugated Container Conference, 1992.

Saunder, G. Philip. "Corrugated Printing Plates: Present and Future", 1992 Corrugated Container Conference, 1992.

Schartz, D. Harvey. "Fingerprint/Press Characterization for Direct Post Print Applications", Corrugated Post-Print Graphics for the Future, University of Wisconsin, Milwaukee, WI., 1997.

Schartz, D. Harvey. "We Bought the Press...Now What", 1994 International Corrugated Container Conference, 1994.

Shulman, J. Joel. "Introduction to Flexo Folder-Gluers", Plainview, New York, NY., Jelmar Publishing Co., Inc., 1986.

Soroka, Walter. "Fundamentals of Packaging Technology", Institute of Packaging Professionals, 1995.

Uppadisakul, Suraphol. "Statistic for Experimental Design", 1980.

Wojcik, S. Michael. "Thin Plate for Corrugated Printing", 1995 International Corrugated Container Conference, 1995.

Wright, P. G., McKinlay, P. R. and Shaw, E. Y. N. "Corrugated Fibreboard Boxes, Third Edition", Australian Paper Manufacturers, 1988.